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OF THE

EIGHTH PACIFIC SCIENCE CONGRESS

OF THE

PACIFIC SCIENCE ASSOCIATION

1953

VOLUME III

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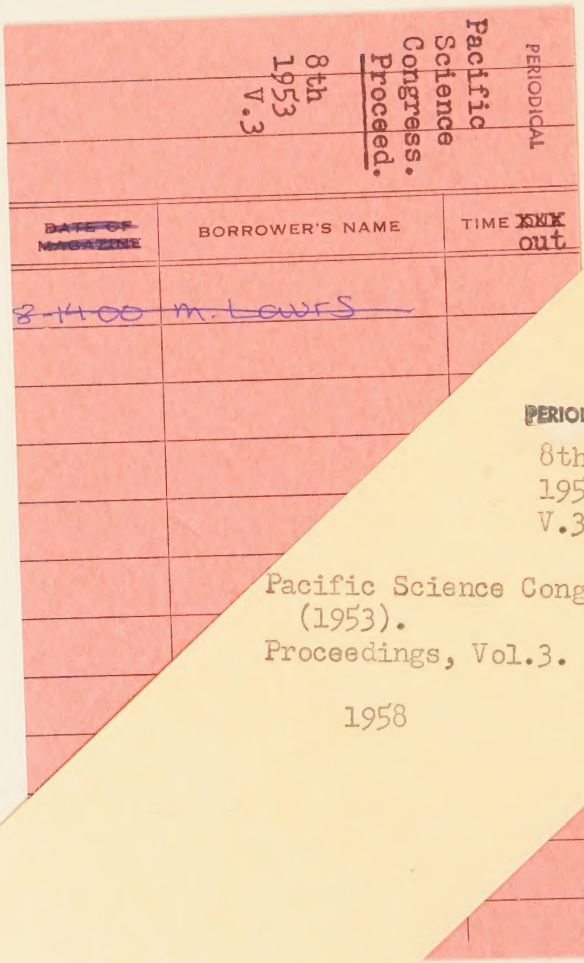

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PROCEEDINGS

OF THE

EIGHTH PACIFIC SCIENCE CONGRESS

OF THE

PACIFIC SCIENCE ASSOCIATION

Held at the University of the Philippines
Diliman, Quezon City
16th to 28th November 1953

UNDER THE AUSPICES
OF THE
NATIONAL RESEARCH COUNCIL OF THE PHILIPPINES
AND THE
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Organizing Chairman: Dr. D. V. Villadolid, Director, Bureau of Fisheries, Manila.
Secretary: Mr. Teodoro G. Megia, Bureau of Fisheries, Manila.*

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RESOLUTIONS ADOPTED IN THE EIGHTH PACIFIC SCIENCE CONGRESS CONCERNING OCEANOGRAPHY

STANDING COMMITTEES

5. That the Standing Committees on Meteorology of the Pacific, Oceanography of the Pacific, Pacific Entomology, Pacific Conservation, Museums in Pacific Research, Soil and Land Classification in the Pacific Area, Forest Resources of the Pacific Area, Crop Improvement in the Pacific Area, Animal Improvement in the Pacific Area, Anthropology and Social Sciences in the Pacific be continued.

JOINT DIVISIONAL RESOLUTIONS

I. *Geology, Oceanography and Meteorology*

The Congress notes the efforts now being made to provide for the establishment of an international geophysical institute in the Hawaiian Islands as a center for the investigation of problems related to the chemistry, physics and mathematics of the earth, sea and atmosphere and their roles in Pacific environmental relationships.

The Congress believes that an institute in the sense envisaged would greatly improve the opportunities for investigation of important geophysical problems.

DIVISIONAL RESOLUTIONS

Oceanography

1. The Congress notes with interest that the oceanographers attending the Eighth Pacific Science Congress propose to establish an Oceanographic Institute of the Pacific.

* *Present address*: Bureau of Agricultural Extension, DANR, Manila.

2. The Congress strongly supports the proposal, recently examined by the special UNESCO meeting of consultants on oceanography, to create a legally constituted inter-governmental organization for oceanographic research in the Indo-Pacific region.

3. The Congress urges member countries (a) to exert every means to develop research programs upon which may be based sound policies for increased development and wise use of marine resources, (b) to develop the fullest international cooperation in the management of marine resources so that they may be maintained permanently.

4. The Congress draws attention to the following types of oceanographic study which can be maintained at a small cost, and whose results when correlated with other available data can provide large returns: (a) Daily observations of surface sea water temperature and salinity which can be made at light-stations, and by commercial shipping lines. The work may be extended to daily observations of the nutrient and respiratory elements, and the state of the sea. (b) Study of specific organisms of academic or economic interest in the locality. There are many species which have been taxonomically described, but whose life history, habits and economic value are unknown.

5. The Congress commends the excellent research work of the Bureau of Fisheries of the Philippines and respectfully suggests to the Government of the Republic of the Philippines that it explore the possibilities of establishing further oceanographic and fish culture research through the provision of extended facilities.

REPORT OF THE STANDING COMMITTEE ON OCEANOGRAPHY OF THE PACIFIC

Prepared by

THOMAS G. THOMPSON,[1] *Chairman;* and
JOHN P. TULLY,[2] *Secretary*

PART I

GENERAL STATEMENTS AND RECOMMENDATIONS

The greatest impetus given to the science of oceanography in the past few years, other than man's unquenchable thirst for new knowledge, has been the desire to increase the food resources of the world which have their origin in the sea. Prior to World War II only a relatively few countries were concerned with the study of oceanography, even though all of the Pacific Science Congresses have continually stressed the importance of exploring and exploiting the seas as a source of food, in order to feed rapidly growing and sometimes hungry populations. The necessity for looking to the sea, which covers about seventy per cent of the surface of the earth, as a source for additional food is now being realized by many political leaders, and other far-seeing individuals in many countries. For the Pacific area this has been especially significant since the 7th Pacific Science Congress. Stressed also is the importance of collaboration for research, conservation and the free exchange of scientific information.

The seas may be searched far and wide, shallow and deep to find the habitats of the fish. This is the historical method. Fish are where you find them. This method is not very efficient for the fish are here today and somewhere else tomorrow.

If dependence is to be made upon the fisheries for an assured food supply, the optimum conditions for each particular fishery must be known as well as when and where such conditions will occur. The adaption of proper and economical fishing methods for the different fisheries in various areas must receive detailed attention and study, although the methods of the commercial fisheries are not in the realm of oceanography.

The oceanographer reasons that the fish will seek those parts of the sea where the food of the fish is most plentiful, where optimum

[1] Professor of Oceanography, University of Washington, Seattle 5, Washington, U.S.A.
[2] Oceanographer in Charge, Pacific Oceanographic Group, Nanaimo, B.C., Canada.

conditions of fertility occur for production of such food, and where the climate of the sea is most suitable. In other words, the oceanographer must provide information as to the nature and extent of the best pastures and the most desirable sea climate. With such oceanographic information, expressed in the form of charts, the commercial fisherman can function economically and efficiently. This oceanographic method is in sharp contrast to the so-called historical or hunting method.

As an example of the oceanographic method, it is deemed desirable to outline its application to recent tuna investigations. The tuna prefer ocean waters where the temperatures are higher than 15°C. and the salinity is greater than $32^{0}/_{00}$. The tuna also require a plentiful supply of smaller fish on which to feed. These small fish are plankton feeders and are found in regions of upwelling near the continental coasts, or around islands, or in some of the ocean currents. These regions of upwelling supply the necessary nutrient material which is essential to plankton growth. Tuna are found in the broad tropical belt of the ocean and can be expected to migrate into some parts of the temperate regions during the summer months. The search for tuna is narrowed to salubrious climates which are well stocked with plankton feeders. Thus the assumption may be made that if the conditions suitable for plankton are known in the warmer seas, there tuna will be found. Hence the oceanographic conditions of the plankton are studied in order to find the tuna.

In this oceanographic approach some progress has been made. It is known that the basic foods are the respiratory elements, oxygen and carbon dioxide and the various nutrient salts such as nitrates, phosphates, silicates, etc.

The respiratory elements are plentiful everywhere in the upper 100 meters of the ocean, but the nutrients are often depleted, except in the regions of upwelling, where they are replenished from the cool depths. Physical oceanographic studies indicate that such regions occur along the coast lines, and around the islands. Here the phyto-plankton is plentiful, and provides food for the zooplankton, which in turn feeds the small fishes on which the tuna feed. Evidently tuna should occur in the warm waters on the lee side of coasts and in the vicinity of upwelling in the equatorial currents. This has been found to be generally true. However, they also occur in many parts of the open ocean where plankton and the plankton feeders are sparse, and so the simple theory of the food chain is not the only explanation of the fishery.

Recently it has been learned that great concentrations of plankton exist in the cold water below the thermocline, over all the known seas. This plankton layer is deepest in the tropics and shallowest in the arctic

and antarctic and it sinks by day and rises at night. This deep plankton layer contains many sizable forms of euphausiids and small fishes, and it is suspected that some of the tuna feed there. If the plankton rise above the thermocline into the warm layers, it would be invading the habitat of the tuna, and they could feed on it. If the plankton rose only to the thermocline, but not through it, it is possible that the tuna would find it. They could make forays into the colder waters, and return to the upper warm waters between feedings. But if the plankton is always well below the thermocline it may be doubtful if the tuna would find it.

Oceanographic data should designate the areas where the deep plankton rise to or through the thermocline. Echo sounders reveal the depths at which the plankton layer exists and also indicate the possible presence of tuna. New types of gear for deep fishing need to be developed or some method devised for luring the fish within the range of existing gear.

This is the oceanographic method. To learn the requirements of the fish; to determine when, where, and how these occur; and then to seek the fish in the most likely places, at most suitable times, and where necessary develop methods of detection and fishing. The last steps are simple, when the biology and oceanography are complete, as shown by the investigations of the Conseil Permanent pour l'Exploration de la Mer, in the North Sea.

This reasoning would be sufficient if extensive knowledge of the plankton were known as well as many details concerning the properties and characteristics of the waters. For most of the Pacific this knowledge is very incomplete. One is confronted with the threefold task of exploring the ocean for tuna, solving the living habits of plankton and charting the properties and characteristics of the water masses.

During the span of the Pacific Science Association, since 1924, the Pacific Ocean has been explored. Many oceanographic expeditions have defined the water masses, charted the currents, recognized the properties of the water, and studied the fish and the plankton. The major water masses, the principal currents, and the generally productive and unproductive areas are known. However, detailed knowledge is very meager. The cycles of temperature, salinity, and productivity, the variations in currents, the migration routes and fluctuations of the fisheries are the present concern.

Research in oceanography is expensive. It requires expensive ships, expensive equipment, highly-trained personnel and a large operational investment. The specialized agencies of the United Nations have realized this and the Food and Agriculture Organization has during the past five years sponsored the Indo-Pacific Fisheries Council, an associa-

tion of 16 member governments of South and East Asia, while UNESCO has, besides providing substantial grants-in-aid to enable plankton workers to attend the forthcoming Symposium to be held in connection with the 5th IPFC meeting in Bangkok, convened, jointly with FAO, the meeting of consultants held immediately prior to this Congress to study the feasibility of promoting a co-operative international oceanographic project for the Indo-Pacific region. It will therefore be seen that there is a tendency for a banding together by many countries of the Pacific area for the study of the sea. Nations that have been dependent solely upon their land resources are now studying their fisheries and exploring their seas, while those nations that have pioneered in oceanographic research have increased their efforts many fold.

At the first meetings of the Pacific Science Association in New Zealand, the report of the chairman of the Standing Committee on Oceanography consisted largely of a review of the principal advances that had been made in instrumentation. The countries of the Pacific were beginning to recover from devastating war and the universities and governmental research agencies were still in the process of readjustment or reorganization. Compared to the present situation little could be said at that time about research accomplishments or planned programs of research.

In most countries oceanography is undertaken by the senior government, in the Fisheries or the equivalent department, with close cooperation of the navy, and the hydrographic and meteorological services. In practically every case the work is directed by a National Committee representing the services, the allocation of effort, resources and personnel. The outstanding exception is the United States, where oceanographic efforts are divided amongst a number of independent agencies, with the universities now tending to play the major role.

One of the important resolutions of the 7th Congress was one urging the establishment of centers for oceanographic education and research in the Pacific area. At the present time such institutions exist in Canada, Hawaii, Japan, and the United States, with full university connection, where contact with experts of all the sciences which can be applied to the study of the sea is possible, and where full library facilities are available. At these universities are oceanographic institutions or academic departments of oceanography. These centers are providing the initiative, inspiration and encouragement necessary to develop young men for the task of advancing oceanographic knowledge. This trend toward the establishment of oceanographic centers in universities is evidenced in other countries of the Pacific area.

The greatest deterrent to the development of oceanography at present is the lack of trained personnel. With the growth of the centers of oceanography the problem of personnel will gradually be solved.

All the peoples of the Pacific are dependent upon the sea, yet the average person is wholly ignorant of this medium. There should be established in the schools and universities of the several nations elementary courses dealing with oceanography. Such courses would be purely of an informative and cultural nature and presented in order to give a general knowledge of the oceans and the many organisms contained therein to the occasional student so that he would be inspired to resume further studies in one of the fields of oceanography.

Since the war many fellowships have been made available which enable students to study in countries other than their own. Experience to date indicates that these fellowships create potentialities for better international understanding than any other system yet devised. This Congress should go on record as urging the establishment of further fellowships, particularly in the several phases of oceanography.

A standing committee of the Pacific Science Association usually consists of six to ten members. The chairman is appointed by the President of the association and has the power to act and name the members of his committee. He works in cooperation with the chairman of the local organizing committee in the preparation of programs and plans for a forthcoming Pacific Science Congress and with the secretariat on other matters. This general plan of operation has many desirable features.

In forming the Standing Committee on Oceanography there are many factors to be considered, chief among which are to secure a proper representation of the various specialities in oceanography and a satisfactory geographic distribution of the members. In selecting the membership of the committee the chairman has sought the advice of many colleagues. He has received suggestions from representatives of governmental organizations, and some oceanographers, eager to further the advances of oceanography, have volunteered their services. Sometime ago the chairman saw the advisability of sub-dividing the committee in order to insure a better specialization of geographic representation. The Standing Committee on Oceanography at present consists of 32 members, which includes the chairman, the secretary and three subcommittees of ten members each. The subcommittees cover the fields of physical oceanography, oceanic biology and the fisheries, and each subcommittee is headed by a chairman.

As the result of experience in forming the present committee, correspondence with several members of the committee and with oceanographers not affiliated with it, the chairman and the secretary have

become convinced of the desirability of forming an oceanographic society of the Pacific. It is suggested that such a society be part of the Pacific Science Association and its meetings would be an integral part of a Pacific Science Congress. The officers and executive committee of such a society, elected by popular vote of the membership, would function for the association in much the same manner as the present standing committee. Through membership in such a society every oceanographer would have a voice and the privilege of active participation. The present standing committee may be criticized as being more or less of a closed system. More than twice the numbers now comprising the Standing Committee were recommended for or volunteered for membership. Then again there are a number of young men just beginning their careers in oceanography who would undoubtedly profit by affiliation with such an organization. This would also be true of oceanographers who are citizens of nations where scientists are relatively few. Such a society could sponsor a much needed oceanographic publication for the entire Pacific area, provided funds could be obtained, in which oceanographers could publish the results of their finding. Here also would appear information of current activities, periodic abstracts of outstanding articles published elsewhere and a current bibliography. It is recommended that such an organization be considered by this Congress.

The 7th Pacific Science Congress meeting in Auckland and Christchurch, had a marked catalytic effect on oceanographic research in New Zealand, and those who came from afar to attend the Congress learned much from their New Zealand colleagues. It was an education to have seen this delightful country and to have been received so generously by its charming people. It is hoped that the oceanographers of the Philippines will receive a similar stimulus and those that have come from afar will be inspired by seeing the Philippines and meeting with the citizens of the country which has played a major role in recent history.

It seems fitting for the chairman and the secretary of the Standing Committee on Oceanography to express their appreciation for the excellent cooperation received from all members of the committee. It has been a real pleasure working with Dr. D. V. Villadolid, chairman of the local organizing committee on oceanography and also chairman of the subcommittee on fisheries. Through his untiring efforts an excellent program has been organized and it promises to surpass even those of previous congresses. To Dr. Villadolid and his associates the Standing Committee expresses its profound thanks and appreciation for their many efforts.

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PART II

A SUMMARY OF PACIFIC OCEANOGRAPHY, 1949–1953

Prepared by

THOMAS G. THOMPSON, *Chairman;* and JOHN P. TULLY, *Secretary*

An attempt will be made to summarize briefly some of the activities and results of oceanographic research since 1949 as reported by the members of the Standing Committee. This summary will be augmented, in some cases, by more detailed reports outlining the programs and accomplishments of a specific country or research organization, and are given as Part III of this report. However, much of the important research that has been conducted will be presented to the congress in the symposia that have been organized under the direction of members of the Standing Committee on Oceanography, and the Philippines Organizing Committee.

AUSTRALIA

The hydrological cycles in the sea around Australia have been studied, the surface and water masses in the Tasman Sea have been identified, and the oceanography of some Australian estuaries have been related to the productivity of oysters. Regular observations between Australia and Antarctica, and at Macquarie and Heard Islands, have been made. A source of deep, very saline water has been found by the Discovery Expedition in the Tasman Sea, which appears to move eastward counter to the circumpolar drift.

A number of oceanographic cruises to 100 miles of the southwest coast were taken in the Fisheries Research Vessel "Warren" to examine the properties of the water. The R.R.V. *Discovery II* examined the properties along the five lines of the southern coast. Surface observations are being secured fortnightly from Australia to New Zealand by the regular passenger ship T.S.M.V. *Wanganella.*

The temperature and salinity characteristics of the surface Tasman Sea water masses have been determined, and their seasonal variation in position will be followed in the future, particularly as they affect coastal waters.

A contribution to the knowledge of estuarine hydrology has been conducted by D. J. Rockford and the work is being continued by detailed dynamic and productivity studies of selected estuaries. This research is primarily directed toward oyster production.

The Australian National Antarctic Research Expedition has maintained physical and biological research stations at Macquarie and Heard

Islands since 1948. Hydrological and biological programs have been carried out, and oceanographic observations have been made between Australia and the Islands, each year, by the relief vessels. The Expedition is to be extended to the Antarctic mainland in the Australian sector.

The biological oceanographic studies have been concerned with developing the unutilized or little utilized aquatic organisms. This includes the discovery of the stocks, fishing tests, life histories, and identification of tuna, clupeoids, carangids, and archibenthic fishes, as well as help surveys.

The Division of Fisheries of the Commonwealth Scientific and Industrial Research Organization carries out a research program in Hydrology and Planktology at its Cronulla headquarters, and at five field stations. This work includes sampling at various coastal stations in eastern and western Australia, which has revealed the hydrological cycles at various latitudes, and a long term trend in the properties and productivity in Eastern Australian waters.

In the fisheries, studies have been made of stock identification, life histories, natural fluctuation, and effects of fishing. These fisheries include barracuda, salmon, humpback whale, western crayfish, sea mullet, scallop, school shark, tiger flathead, white bait, and other indigenous fishes.

Considerable work has also been done on the acclimatization and culture of rock, pearl and Japanese oysters, the introduction of freshwater trout, and the enrichment of inland waters. Estuarine ecology has received some attention with a view to increasing fish production.

No institution in Australia gives special training in oceanography, but the Department of Zoology in a few Universities gives lectures on marine organisms and ecology; and there are small research projects on marine animals for post graduate students.

CANADA

A series of surveys has been undertaken for about 500 miles of the coast to examine the currents and the properties of the water to a depth of 1000 metres. This area of British Columbia is where the North Pacific drift divides, part flowing north to form the Alaska gyral and part south to form the California current. Coupled with the Marine Life Research Surveys off the coast of the United States, this work provides for the first time a realistic picture of the detail of this great divergence which has been recognized for a long time. The currents are weak (less than 10 miles per day) and mostly eddies.

The salinity structure is definite and appears to be permanent. There is an upper zone of low salinity water to about 100 metres depth, a deep zone of greater salinity, separated by a boundary or transition

layer of ten to 100 metres thickness. In late winter the temperature stratification is similar to the salinity. When the surface waters are heated in the spring a warm layer is formed which gradually deepens and becomes more marked as the season advances. When autumn cooling occurs the warm layer loses heat, but continues to deepen until it coincides with the salicline in late winter. This area is being continually monitored by regular bathythermograph observations from the weather ship on Station Peter.

The principal interest is in the coastal waters and the many bays, sounds, inlets and straits which are the dominant feature of the Pacific coast. The area is divided into natural regions. Each region is surveyed at frequent intervals throughout a year or more, until the properties of the water and the mechanisms of circulation, and their seasonal variations are revealed. These are then related to daily observations of surface sea water temperature, weather and run-off that are being made concurrently around the coasts. These daily observations then serve as continuing indices of the oceanographic conditions. Both the oceanographic conditions and the daily observations have been successfully related to some of the fisheries.

The prediction and control of industrial and domestic pollution in coastal areas had become a major oceanographic concern. As new industries are established their effect on fisheries is forecast and the disposal of sewage adjusted to avoid harmful pollution.

This work is under the direction of the Joint Committee on Oceanography in Canada, which all government departments interested in the sea, pool their requirements and resources. The Committee directs the work of a group on the Atlantic Coast and another group on the Pacific Coast, in physical and chemical oceanography. The Fisheries Research Board of Canada operates five stations studying fisheries and two stations studying the utilization of marine products. In addition there are a number of National and International Groups conducting oceanographic and fisheries research in particular areas, and on particular problems.

The charting of coastal waters and forecasting of tides and tidal currents is done by the Hydrographic Service.

The Institute of Oceanography at the University of British Columbia is the only place where Oceanography is formally recognized, although a number of universities conduct sea researches. The Institute offers post-graduate courses in the application of the various sciences in the sea leading to advanced degrees in those sciences.

Publication is provided in the Journal of Fisheries Research Board of Canada, and a manuscript series from each oceanographic group and the Institute of Oceanography.

CHINA

In spite of tremendous difficulties there are some observations of sea water temperature, and some fisheries studies being made. There are plans to establish a research center for fisheries and oceanography which will unite all the work.

DENMARK

The Galathea Expedition fished in the bottoms of the Kermadec, Solomon, Banda, Java and Philippine deeps and found a variety of animals and live bacterial cultures right down to 10,000 metres depth. Temperature and salinity samples were also taken, and production of organic matter was studied by means of Carbon 14.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

This organization sponsored the creation of the Indo-Pacific Fisheries Council. It is evident that oceanographic research in the tropical regions of Asia has been scanty. The lack of knowledge in the Western Pacific and Indian Oceans is one of the largest gaps in the scientific exploration of the earth. The Indo-Pacific Fisheries Council has undertaken to promote the exploration and utilization of the fisheries of this region by member governments. Oceanography is an essential feature of the program. Australia, India, Indonesia, Japan, New Caledonia and the Philippines have conducted oceanographic programs in their own coastal waters. The Galathea Expedition from Denmark explored some of the waters of the Indian and Western Pacific waters, particularly the great depths. However, it seems that no organization is ready to undertake the over-all sustained exploration and research which is required to exploit the potential food supplies in these seas. The Indo-Pacific Fisheries Council proposes that all the countries in the area coordinate their efforts and pool their results so that each may profit from the work of all. A meeting which some of you attended was held a few days ago to discuss this project. If such a plan can be put into effect, it may well equal the excellent work of the Conseil Permanent pour l'Exploration de la Mer, and add materially to the food resources of southeastern Asia. The growing interest in oceanographic research by the countries of the south and southwest Pacific and the activities of the Indo-Pacific region seem most promising.

GREAT BRITAIN

From October, 1951, to January, 1952, the Royal Research Ship *Discovery II* made oceanographic surveys between Australia and Antarctica. The primary object of this work was to fill in the gaps left by the pre-

war survey of the Discovery Committee. The properties of the water and the plankton were observed. It appears that there may be a source of deep, very saline water in the Tasman Sea moving eastward, counter to the circumpolar drift.

In 1950, H.M.S. *Challenger* made an extended cruise across the Pacific Ocean. Echo soundings, temperatures, and water samples were taken to 3500 meters depth. The bottom morphology and submarine geology were studied by samplers and seismic methods. Magnetic observations, plankton hauls and bird observations were also made.

HAWAII

The Department of Zoology in the University of Hawaii maintains a biological station from which studies of the surrounding seas are conducted. These are particularly concerned with the occurrences and catching of white bait. Recent researches have shown that tuna are attracted and induced to school by certain extracts of tuna and other fish. This is a major discovery which may well revolutionize the fishing techniques.

HONGKONG

A Fisheries Research Unit has been set up within the precincts of the University of Hongkong. Financed from Colonial Development and Welfare Research funds, the Unit is housed in the Northeast Science Building. Such also contains the Departments of Biology and Physics.

The Fisheries Research Unit is staffed by a Director, a Chief Scientific Officer, and three Assistant Scientific Officers. A steel-hulled modified timber on the diesel power is under construction as a research vessel and will be launched under the name of "Alister Hardy" on 27 November 1953.

The research programme of the Unit is in course of formulation, and researches on (i) the biology of three of the most important commercial species of fish, (ii) the biology and pond cultivation of grey mullet, (iii) the methods and organization of freshwater fish culture, and (iv) the occurrence and distribution of freshwater and reservoir algae have been initiated. These will be supplemented by a preliminary oceanographic programme as soon as the research vessel has been commended.

INDIA

While not one of the Pacific nations, oceanographic investigations in India will be of importance in the immediate future because of the Indo-Pacific Fisheries Council. Until recently, very little attention has been given to oceanographic investigations. The Government of India

constituted the Central Board of Geophysics early in 1949, and a special committee on oceanography functions under this board. Oceanographic studies have been initiated in the Central Marine Fisheries Research Station and by the Indian Meteorological Department. Investigations of the latter deal particularly with turbulence and microseismic waves. Continuous tidal stations are maintained by the Indian Survey. The Indian Navy has conducted researches on underwater sound and the vertical thermal structure of the sea.

The teaching of oceanography is carried on at Andhra University where physical oceanography is given in the Geophysics Department, marine geology and marine zoology in the respective Departments of Geology and Zoology.

INDONESIA

In 1948 an oceanographer, Mr. C. Ph. Veen, was attached to the Laboratory for Investigation of the Sea at Djakarta. As there were no sufficient instruments available at that time and as there was no vessel available, only surface salinities were taken into consideration.

This was done with the help of lighthouses, taking daily samples, and with the help of merchant ships. These merchant vessels take a sample of sea water every month, wherever they may be. Gradually this service grew and nowadays there are about 125 ships concerned in the work, bringing in 42000 samples of water yearly to the Laboratory. Two Dutch and one Danish shipping companies are involved.

In the beginning only Indonesia waters were considered but later it became clear that for a thorough understanding of what was happening with the currents during the different monsoons, an extension proved to be unavoidable. So nowadays samples are collected even in the Indian Ocean to the South and West of Indonesia and beyond the Torres Strait in the East and to the northwest in the China Sea up to Formosa.

Out of all the data collected, monthly charts of salinities were mapped and three monthly means were drawn up for the full West and East Monsoon and for the times between.

This was published up to 1951 in the periodical OSR NEWS and a second publication was made wherein all data of Schott, the Snellius and other sources were taken into consideration. This too was published in the OSR NEWS.

In 1952 a research vessel, the "Samudra," was put into commission, given to Indonesia by the FOA administration of the United States, meant chiefly for the use of fisheries exploration but fully equipped for oceanographic research. It is too early now to give results.

The biologist devoted some time to the work of the Indo-Pacific Fisheries Council, an international council sponsored by the FAO. Most

of the time was devoted to teaching and to training young Indonesians out of college, who wished to become assistant marine biologists. The result proved to be heartening.

JAPAN

This island nation with its dense population is actually dependent upon the sea for its existence. It is not surprising, therefore, that the science of oceanography has received more encouragement to develop here than in any other country of the Pacific area. Courses are offered in the various phases of oceanography in many universities and much fundamental, basic research has been conducted by professors in these institutions.

Japan has approached oceanography from the standpoint of fisheries, meteorology, and hydrography, and all investigations and observations have been coordinated by a Marine Research Council. All fisheries resources are receiving intensive study. The Meteorological Service makes numerous daily records of the sea water temperatures. The Hydrographic Office and Maritime Safety Agency is concerned with the charting of the seas and coasts, the tides, tidal currents, and tsunamis. The considerable resources of each agency are available to the others through the coordination council.

There are eight Fisheries Research Institutions, the Hydrographic office, and five principal Meteorological observatories, and at least ten research ships. Each department has a series of journals which provide for publication of data, researches, and studies.

In addition to these observing and applied research groups, the theoretical aspects are studied in the Geographical Institute, and in several universities. The Oceanographical Society of Japan provides a meeting place for the scientists and publishes a technical quarterly journal.

Japanese oceanographers are studying the behaviour of the north flowing warm Kuroshio and the south flowing cold Oyashio, which are the dominant currents among the ocean currents. The advance of the Kuroshio in the summer, its retreat in winter, and its meandering are complementary to the Oyashio's.

A similar balance of currents occurs in the Sea of Japan, but with different emphasis on the cold and warm water masses. This cold water on the Pacific side may be invaded by warm water through Tsugaru Straits. These circulations are dominated by seasons and winds, and the coastal regions are modified by tides. Oceanographers are describing the character and behaviour of these water masses, which are of major concern to the fisheries and climate of Japan.

In coastal waters the tides, tidal currents, waves and tsunamis are being studied so that they may be forecast for the safety of vessels and coastal populations. The physical and chemical properties of the waters and their fluctuation with season, weather, and state of the sea, are important to fisheries and are being studied in all areas. The total of this work is enormous.

The Japanese have given much attention to the development of methods, equipment, and material for oceanographic research. Standard sea water comparable to Copenhagen water is being produced. Reversing thermometers are being manufactured, and many new instruments have been designed such as recording current meters, wave recorders and computers, bathythermographs, and a bathysphere.

MALAYA

Le Mare and Tham, in Malaya, have made a statistical analysis of the relation of physical and chemical factors with the quantity of trap-caught fish. They considered wind, rainfall, temperature, salinity phosphate and plankton pigment in relation to the catch of anchovy, sprat, dorab and Spanish mackerel in the Singapore Straits, and solved a regression equation for the independent variables. With this they predicted the monthly catch through 1948 and 1949 within twenty percent.

Admittedly their situation is particularly suited to these analyses, but they are, nevertheless, to be congratulated in solving this direct relation; and their methods may well be extended to similar fisheries elsewhere.

This is an instance where one of the ultimate objects of oceanography has been accomplished.

NEW CALEDONIA

The Laboratoire Oceanographique de l'Institut Francais Oceanique (The Oceanographic Laboratory of the French Ocean Institute) is undertaking a large fisheries research program, with financial aid of the South Pacific Commission.

The Muséum National d'Histoire Naturelle of Paris has sent Professor Ranson to Tahiti to study the production of pearls and shell, and to determine the best methods of exploitation. He has introduced modern methods of oyster culture with encouraging results.

NEW ZEALAND

Prior to the 7th Pacific Science Congress, there was little organized oceanographic research, although a number of individuals were actively engaged in various studies. Recently an intensive hydrographic survey program, which also includes regular observations of waves and of

the properties of coastal waters, was undertaken. In 1950 the New Zealand National Committee on Oceanography was formed as an advisory body to the Council of Scientific and Industrial Research. It has operated in effecting liaison, sponsoring research projects and in advising the New Zealand government on oceanographic matters. In the field of physical oceanography, arrangements were made for the preparation of a bathymetric chart of adjacent seas, for the collection of continuous echo sounding profiles, particularly on voyages between New Zealand and Australia and outlying islands. Cooperation was given to several extensive expeditions working in the Antarctic and South Pacific areas. Many programs in oceanic biology have been inaugurated by several of the universities.

PACIFIC OCEAN FISHERIES INVESTIGATION

An extensive series of investigations is in progress dealing with the physical, chemical, and biological properties of waters of the Central Equatorial Pacific along with experimental fisheries operations. This is an effort to evaluate the situations in which fish, particularly tuna, are present or absent. They have described the water structure of the north and south equatorial currents, and the counter-currents between them; have found a subsurface counter-current and a mid-ocean region of upwelling with high phosphates and much plankton. On the basis of these encouraging reports their work is being intensified. Much data has been collected in Hawaiian waters but has not yet been analyzed.

PHILIPPINES

From 1947 to 1950 oceanographic investigations were made in the Sulu and Celebes Seas by the Fish and Wildlife Service of the United States under the Philippine Fishery Program. During that period 526 hydrographic stations were occupied. Observations made at each station included temperature, salinity, dissolved oxygen, phosphate, nitrate, hydrogen ion, and silicate. The observations extended generally to a depth of 2000 meters and in some cases to a depth of 4000 meters.

The waters surveyed included the Celebes Sea, the Sulu Sea, all of the smaller seas of the Philippines, the nearby waters of the South China Sea, and the waters of the Pacific east of the Philippines to a distance of about 300 miles from shore. Most of the areas were surveyed twice; once during the northeast monsoon and once during the southwest monsoon.

Following the termination of this operation in June, 1950, the U.S. Agency turned over a small ship and some oceanographic gear to the Bureau of Fisheries of the Philippines.

Monthly surveys of selected areas have been made throughout a year or more to determine the cycles of oceanographic conditions and their relation to wind, weather, and season. Daily observations of sea water temperature and salinity are made at three shore stations. Water and air temperatures are collected by ocean shipping.

SOUTH AMERICA

For the vast oceanic areas in the eastern Pacific, off the coasts of South and Central America, organized programs of research have been exceedingly limited. However, in the past several years the Food and Agriculture Organization of the United Nations has done much to initiate and stimulate investigations in oceanography and particularly in fisheries.

The first part of an atlas of the coastal current of Peru and a series of monthly maps of the Peruvian littoral with indications of the average sea-surface temperature, air temperature, barometric pressure, wind direction and force for the years 1946 to 1951, have just been published. The Guano Company has installed a central department of oceanography and ichthyology in their main office in Lima, from which three biological stations are administered. One station deals with the behaviour of oceanic birds, another is concerned primarily with plankton studies and the third with the biology of the anchovy. The Peruvian Navy as well as the Guano Company has cooperated with recent oceanographic expeditions in the eastern Pacific operated by the Scripps Institution of Oceanography and by Yale University. Educational work in Oceanography is just beginning. The Geographic Institute of the University of San Marcos recently gave a series of lectures on oceanography. The attendance in these lectures has been primarily graduates of the university who are teachers in the Peruvian public schools.

Pure oceanographic research has not been conducted to any extent by Chilean investigators, the tendency being to study the sea as the habitat of organisms of commercial value. However, considerable basic data have been collected by the Chilean Navy and by merchant ships. Two biological stations, one operated by the University of Chile at Montemar and the other by the University of Concepcion in south central Chile, give promise of undertaking oceanographic research in the immediate future, due to the activities of representatives of the Food and Agriculture Organization and the Chilean Navy.

The Food and Agriculture Organization and the Centre of Scientific Cooperation of UNESCO for Latin America are studying ways and means of organizing an international network of marine laboratories in Latin America. Laboratories on the Pacific coast will stress investigations of

the Humboldt and El Niño Currents. The cold Humboldt Current as well as the warm countercurrent of El Niño has a strong effect in the distribution of fishery resources as well as the climate of western South America. A regional fisheries council is being organized for South America, and attention is being given to the establishment of centers for the training of personnel to engage in fisheries and oceanographic investigations.

THAILAND

Oceanographic work is just beginning. Tidal observations are being made, sea water temperatures and salinities are being observed, and a fisheries research laboratory is being established. Trained personnel are required to lead this work.

The Hydrographic Service of the Navy has a division of oceanography which is mainly concerned with the preparation of Annual prediction of tides and tidal currents in the Gulf of Thailand.

Some salinity data has been collected near the mouth of the river at irregular intervals during the past two years.

The Department of Fisheries established a Marine Station at Bai Be Rayong in 1953. The program has not yet been established.

It is hoped that the Hydrographic Service and the Department of Fisheries will co-operate in the collection of temperature and salinity data in the Gulf of Thailand, especially in the areas of the river mouths.

UNITED STATES OF AMERICA

Programs in oceanography are carried out more or less independently by services of the federal government, by organizations or bureaus of the several states, and by some universities.

The U. S. Coast and Geodetic Survey is occupied primarily with the charting of coastal areas, tidal studies, and investigations of tidal and nontidal currents. The Fish and Wildlife Service is concerned with oceanography in relation to fisheries and have conducted a large number of investigations in Alaska, Hawaii, the Trust Territories of the Pacific and off the Pacific coast of the United States. Numerous projects of the U. S. Navy are in progress and much fundamental research is sponsored by the Office of Naval Research through grants to universities. Planning of oceanographic studies is made by the Hydrographic Office of the U. S. Navy and this organization serves as a general clearing house for much oceanographic information. The U. S. Coast Guard has cooperated in furthering various studies. The National Academy of Science and the National Research Council have done much to stimulate oceanography in the United States.

Two international commissions, the International Halibut Commission and the International Salmon Commission, both established by treaty between the United States and Canada effectively operate in the conservation and studies of these two fisheries.

The U. S. Fish and Wildlife Service, the California Academy of Sciences, Hopkins Marine Station of Stanford University, the California Fish and Game Commission, and the Scripps Institution of Oceanography of the University of California, have sponsored the Marine Research Committee. Working with three ships and a large staff this project has observed the currents, the properties of the water, and the marine organisms within a limit of 300 miles off the California coast in connection with studies dealing with the life history and habits of the California sardine. These investigations have also contributed materially to the blue fin tuna.

The Scripps Institution of Oceanography, located at La Jolla, a part of the University of California, offers a series of graduate courses in practically all of the branches of oceanography. This institution, since the last Congress, has conducted several extensive exploratory expeditions over much of the Pacific area.

In California attention has been given to coastal wind phenomenon, the nature and extent of upwelling, studies of waves, beach erosion, submarine canyons, sea mounts and the various oceanic fisheries.

The University of Washington with its laboratories in Seattle and at Friday Harbor now offers undergraduate training in oceanography in addition to extensive graduate work. The research activities are primarily concerned with the oceanography of the coastal waters of the State of Washington, and the oceanography of numerous straits, sounds and estuaries. There is considerable cooperation between the Department of Oceanography and the School of Fisheries.

Because of the great industrial development and increasing population, the United States is faced with problems arising from the pollution of coastal waters. Methods of predicting pollution and of utilizing local sea currents to effectively remove such pollution have been devised.

In general, the United States is examining all phases of oceanography in their own coastal waters with particular emphasis on the mechanisms of currents, and waves and their variation with season and weather, as well as their relation to fisheries. Detailed studies of the bottom topography, submarine geology, properties of the water, and general oceanographic processes have been conducted. In addition, many transocean expeditions have been and are being made to all parts of the world to increase the knowledge of structure, properties of the water, currents, depths, bottom material and marine organisms.

The results of all of this work are available in special publications from the various institutions, State and Federal publications, and the journals of the learned societies.

A series of investigations on fish poisoning and poisonous fishes of the tropical Pacific have been in progress at the School of Tropical Medicine at Loma Linda, California. These studies emphasize the necessity of toxic fishes and the nature of ichthyosarcotoxins. Lack of such knowledge tends to hamper the economic development of the shore fisheries of the tropical Pacific.

VIET-NAM

The 1949-53 period has been marked by a slowing of activities as related to the constitutional modification arising from the transfer of the Institute to Viet-Nam, and with the strife in the Territory.

An increase in activities started in 1952–53, and a more marked increase is expected in 1954. The Institute presently has two laboratory chiefs. There will be four in 1954. Temporary foreign researchers are also requested for the laboratory.

The work presented during the period was more particularly directed toward the investigation of the flora and fauna of Viet-Nam. A science Museum for this fauna containing actually 30,000 specimens or 3,000 species has been established. Study of the fisheries has also been overtaken, most particularly in the field of the technical knowledge of fishing gear at Viet-Nam.

The results of the work have been the subject of more than 20 publications of varying importance, appearing either in the publications of the Oceanographic Institute of Nhatrang or in foreign publications.

WESTERN SAMOA

The observatory of Apia is under the control of the Department of Industrial and Scientific Research, New Zealand. Investigations are undertaken in meteorology, terrestrial magnetism, seismology, and in more general fields such as tidal predictions. As far as oceanography is concerned the Observatory records the heights and times of tides and the daily sea temperature and density. These results are forwarded to the U. S. Coast and Geodetic Survey. The Observatory is also undertaking some experimental work on a solar still for the New Zealand Reparation Estates in Samoa.

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PART III

REPORTS ON ACTIVITIES OF SPECIFIC COUNTRIES ON RESEARCH ORGANIZATIONS

OCEANOGRAPHIC RESEARCH IN AUSTRALIA SINCE 1949

By H. Thompson

1. *Research Programmes in Progress*

In each of the Australian Universities small research projects on marine animals are being undertaken by post graduate students in the various Departments of Zoology. These are not to be regarded as portions of an integrated programme of oceanographical research. Each of the six state Departments of Fisheries is concerned mainly with the administration of Fisheries Acts, but each undertakes some biological research on particular fisheries problems.

The Division of Fisheries of Commonwealth Scientific and Industrial Research Organization at its headquarters, the Marine Biological Laboratory, Cronulla and at five field stations in various parts of Australia carries out a research programme in the following sections: (1) Oceanography including Hydrology and Planktology, (2) Biology including studies of fish, crustacea, shellfish, and whales, (3) Microbiology, (4) Underwater fouling of ships and structures.

2. Division of Fisheries, C.S.I.R.O. P. O. Box 21, Cronulla, N.S.W.

3. No institution gives specific training in oceanography though the Department of Zoology of each University gives lectures on marine organisms and ecology.

4. Australia as a member government of United Nations F.A.O. has maintained a close link with the Indo-Pacific Fisheries Council. Representatives have been sent to each of the meetings of the Council and at the 3rd and 4th meetings the Australian delegate was Chairman of Technical Committee I.

5. Summary of research results of C.S.I.R.O. Division of Fisheries.

i) *Oceanography*

Oceanic studies. F. R. V. "Warren" has carried out a number of oceanographical cruises in S.W. Australian waters. $S\,{}^{0}/_{00}$, O_2, Inorganic P, Organic P, and Nitrate N. The results of these surveys are given in volume 3 of Oceanographical Station Lists.

R. R. V. "Discovery II" in 1950–51 worked 300-mile section lines, are off Sydney, Eden, Pt. Culver, Albany, and Rottnest Island. The data are not yet published but certain results are given in a paper entitled "A Comparison of the Hydrological conditions off the Eastern and Western coasts of Australia." (I.P.F.C. Section II Proc. Madras meeting.)

Through the courtesy of her owners, the T.S.M.V. "Wanganella" is now collecting surface salinity and temperature observations on her regular fortnightly cruises from Sydney to New Zealand.

The salinity temperature characteristics of the surface Tasman Sea water masses have now been determined and their seasonal variation in position, particularly as they affect coastal waters, will be followed in the future.

ii) *Coastal Studies*

The monthly sampling at various coastal stations in Eastern and Western Australia has been continued. A very interesting long term trend in productivity and other hydrological characteristics is now apparent in E. Australian coastal waters during the period 1942–1952 and an account of this phenomenon is now being prepared for publication. The annual hydrological cycles at various latitudes along the Eastern Australian coasts have now been established. A paper is being prepared giving a comparative study of these annual cycles. This coastal data up to 1950 are contained in volume 4 of O.S.L.

iii) *Estuarine Hydrology*

Since the publication of the comparative results to date of estuarine hydrological studies, (A.J.M.F.R. Vol. 2 No. 1 June 51,) these studies have concentrated on the detailed dynamics and the productivity features of selected estuarine systems. The productivity characteristics of the intertidal region particularly in relation to oyster production, have been intensively studied and a generalized account of this work appeared in Rapp. et Proc. Verb. Vol. 131, 1952-C.I.E.M.

Australian Fisheries Biology Since 1948

A. *Unutilized or little-utilized stocks of aquatic organisms* (discovery, fishing tests, stock identification, life histories, fluctuations):—

(i) *Tunas.* As small fishery for *Thunnus thynnus maccoyi,* the outcome of investigations and fishing tests in the previous decade began in southeastern waters. It is becoming evident that shoals of this species may occur further out to sea than was once supposed, and are sometimes scarce near the coast. These fluctuations in availability are being studied. New facts about the distribution of *Katsuwonus pelamis* in southeastern waters, including its apparent preference for wa-

ters of 16 to 18°C., were brought to light. A survey of tropical Australian waters in the latter half of 1949 showed *Kishinoella tonggol* and *Euthynnus alletteratus* to be the most abundant tunas. In the waters of Australian New Guinea the principal species appear to be *E. alletteratus* and *Katsuwonus pelamis.*

(ii) *Clupeoids and carangids.* The existence of several stocks of *Sardinops neopilchardus* and *Engraulis australis* was demonstrated. Problems of age-determination from scales of *Sardinops* were studied. As a result of previous investigations a small fishery arose on one stock of *Sardinops* in southwestern Australia. Echo sounder traces of shoals of *Sardinops, Engraulis,* and the carangid *Trachurus novaezelandiae* were identified.

(iii) *Archibenthic fishes.* The larger teleosts and elasmobranchs of the continental slope, at depths of about 200 to 800 metres, are being investigated by long-lining in southeastern waters.

(iv) *Algae.* Studies were made of the availability of the giant kelp *Macrocystis pyrifera* and its rate of regeneration after cutting.

(v) *Other exploratory investigations* included: Continuation of surveys of fish resources in New Guinea, the northwest, and elsewhere; a special survey of unutilized stocks of Palinurid crayfishes in northwestern waters; and attempts to locate reported new beds of pearl oysters (*Pinctada*) in the northeast.

B. *Utilized stocks* (stock identification, life histories, natural fluctuations, effects of fishing):—

(i) *Barracotta* (*Thyrsites atun*). Progress was made with the identification of different stocks, all of which appear to be under-fished. Considerable seasonal changes in bodily condition were observed.

(ii) *Australian salmon* (*Arripis trutta*). Progress was made with the identification of different stocks. As a result of previous investigations two salmon canning firms now use aircraft to locate shoals. There are no clear signs of over-fishing.

(iii) *Humpback whale* (*Megaptera nodosa*). The fishery revived on the west coast of Australia and commenced on the east coast. Biological data are being obtained at whaling stations. The length of this whale at first maturity appears to be less than was previously thought.

(iv) *Western crayfish* (*Palinurus longipes*). The fishery expanded greatly, partly as a result of previous scientific surveys of the resource. Studies were made of intraseasonal migrations of crayfish from deep to shallow water, and across the shallows. As with the preceding stock, the possible necessity for future control of exploitation is being borne in mind.

(v) *Sea mullet* (*Mugil cephalus*). Attention is still being given to the possibility that the eastern and western Australian stocks are being overfished, but the most recent work is somewhat reassuring.

(vi) *Scallops* (*Notovola meridionalis*). The stock of the D'Entrecasteaux Channel, Tasmania, is declining, apparently by natural fluctuation. Biological observations were made by diving.

(vii) *School Shark* (*Galeorhinus australis*). Tagging experiments revealed the existence of a single large stock in southeastern waters. It is declining under fishing and conservation measures have been recommended. Growth and reproduction rates are slow.

(viii) *Tiger flathead* (*Neoplatycephalus macrodon*). The study of this species was continued, with special attention to growth and recruitment. Availability has greatly declined over the last thirty years of intense trawl fishing on the east coast, depleting is presumed, and conservation measures have been recommended.

(ix) *Whitebait* (*Louettia seali*). Two stocks of this small anadromous salmonoid were identified in Tasmanian waters. One now appears to be depleted after heavy fishing and the other is under-exploited.

(x) *Other fishes* which are being studied include *Nemadactylus macropterus. Trachichthodes affinis, Mylo australis, Cybium commersoni, Chrysophyrs auratus, Arripis georgianus* and the elasmobranch *Emissola antarctica.*

C. *Acclimatization and culture of stocks:—*

(i) *Japanese oyster* (*Ostrea gigas*). This species was successfully acclimatized, to the point of good growth and reproduction, in Tasmanian waters. Further importations are being made.

(ii) *East Coast rock oyster* (*Crassostrea commercialis*). Work to improve the already efficient oyster culture of New South Wales waters has been continued and efforts have been made to introduce oyster culture into other areas.

(iii) *Pearl oysters* (*Pinctada* spp.). The possibilities of culture are being investigated in Torres Strait. Growth and reproduction of oysters of natural beds are being studied as a prerequisite.

(iv) *Introduced freshwater trout* (*Salmofario* and *S. iridens).* The possibility of maintaining certain populations without further planting of hatchery stock is being investigated.

(v) *Enrichment of inland waters.* A substantial flora and fauna was developed in a barren mountain lake as a result of addition of nutrients. It is now intended to study the effect of the introduction of fish.

(vi) *Estuarine ecology.* Preliminary steps were taken to implement a programme of ecological studies in east Australian estuaries and lagoons. It is considered that there are possibilities of increasing fish production in these waters by control of environment of fish populations or both.

D. *Fouling of submerged structures:—*

The principal fouling organisms of the east coast were identified, and attention is being given to periodicity of settlement and rates of growth.

Antarctic Research

The Australian National Antarctic Research Expedition has maintained physical and biological research stations at Macquarie and Heard Islands since 1948. The oceanographic work at Heard Island has comprised a survey of the plankton and hydrological conditions in the region of the island and a programme on marine fouling problems. Because of the hazardous boating conditions at Macquarie Island very little work on plankton and hydrology has been attempted there. However, some plankton hauls have been done and a programme of littoral ecology is being carried out.

Sea water temperatures have been taken at three-hourly intervals during the voyages to and from Australia by the relief vessels which visit the islands each year.

Sea elephants and sea birds visit these islands in large numbers to breed. The biology of these animals has been studied in some detail, wholesome work has been done on visiting species, such as the Leopard Seal. Reports on these projects are being compiled and will be published in the Expedition's own series of publications.

The main feature of the biological programme for the immediate future is a limnological study at Macquarie Island.

The Australian Government has approved an extension of the Expedition's activities to the Antarctic mainland, in the Australian Sector. The programme for the summer of 1953–54 covers investigations of a preliminary character in geographical exploration and mapping, and the main investigations in physics, geophysics, and biology will commence in the second year.

BRITISH CONTRIBUTION TO THE OCEANOGRAPHY OF THE PACIFIC OCEAN

By G. E. R. Deacon

The Royal Research Ship 'Discoverey II' worked two lines of stations across the East Australian Current in October, 1950, and another line across the Tasman Sea to Wellington in the same month. In November she cruised southeast across the southern end of the Kermadec Trench to the Chatham Island plateau and into deep water as far as 45°S 150°N. Observations were then made as far as the northern edge of the pack-ice in 60° 46'S, before she turned westward along the ice-edge to 63°S 175°E and northward back to New Zealand. After more observations between New Zealand, Macquarie Island and the ice-edge, and several lines of stations in the southern Indian Ocean and south of Australia, another line was worked across the southern part of the Tasman Sea. This was followed by observations across the South Pacific Ocean, touching the ice-edge in 66°S 141°E and 64°S 78°W.

The observations in the southwest Pacific Ocean give some support to an earlier indication that the deep water east of New Zealand is slightly more saline than the deep and bottom water south of the Tasman Sea, and revive the question of a possible weak source of highly saline deep water north of New Zealand. It is particularly difficult to draw conclusions about possible deep-water movements in this region from the distribution of temperature and salinity because the salinity differences below 2000 metres are very small. The same is true in the deep water southwest of Cape Horn, where the data give a possible indication that the eastward circumpolar drift may be offset to a small extent by a movement of deep water from the Atlantic Ocean.

The similarities between the deep and bottom waters of the Tasman Sea and those of the Southern Ocean indicate that there is no effective barrier between them. Echo soundings between the New Zealand shelf and Macquarie Island show a very rugged bottom at moderately great depths, but give no evidence of a connecting ridge such as is drawn tentatively on some maps.

Vertical and oblique hauls were made down to 1500 metres at the same time as the physical and chemical measurements, and records made of the sighting of whales and birds. The primary object of the work was to fill in the gaps of the oceanographic survey of the Southern Ocean made by the Discovery Committee before the last war. The data are being prepared for publication.

H.M.S. 'Challenger', one of Her Majesty's surveying vessels, made an extended cruise across the Pacific Ocean in 1950–51, taking echo

soundings, temperatures and water samples down to 3500 metres, and carrying out investigations into morphology and submarine geology with the help of samplers and seismic methods. Magnetic observations, plankton hauls and bird observations were also made.

Observations on the ascent and descent of the sound scattering layer at sunset and dawn were plotted against light intensity measured by a Secchi disc. They suggested that the migrations depended only on light intensity with no regard to temperature gradients. The rate of descent averaged 14 feet per minute; the ascents were more variable, small groups of scatterers appearing to rise ahead of others, and the rate varied from 9 to 3 feet per minute. In 40°N 148°E photographs were taken of a a short-tailed albatross (*Diomedia albatrus*) which had been considered extinct for the past 15 years.

A bottom sample was obtained from a depth of 5744 fathoms in the Mariana's Trench. It has been described by the British Museum (Natural History) as "dark brown ooze containing many remains of diatoms and radiolaria."

CANADIAN PACIFIC OCEANOGRAPHY SINCE 1949

By John P. Tully

Since the last Pacific Science Congress, Canada has made considerable progress in oceanography. The nature and scope of our problems have been recognized. The plans for research and education have been established. The oceanographic resources have been organized. It will be sufficient to show you the high-lights of our problems, work, and organizations, and refer you to the bibliography for the details.

Canada fronts on the Pacific, the Arctic and the Atlantic Oceans, which are completely different in character, climate, and behavior. We do not have the resources to conduct complete programs in all three at the same time, but we have managed to get the essential work done. If the total Canadian effort were concentrated in any one of these oceans, it would be one of the world's major programs. However, the development of our fisheries, industries, and sovereignty has made increasing demands for information, particularly in the coastal approaches.

A short description of the principal oceanographic features of these three oceans will help you to appreciate the magnitude and diversity of the Canadian problems.

The Canadian Arctic is completely ice-bound from November to June each year. As the ice in Hudson's Strait and Baffin Bay breaks up, it is carried southward, by the Labrador Current, to meet the Gulf

Stream off the Atlantic Coast of Canada. Hudson's Bay is an inland sea, similar in many respects to the Baltic. It is shallow, the waters are brackish, and the ice melts where it is during the short, hot summer.

This melting, and the annual migration of ice out of the Eastern Arctic leaves a summer sea route open into Hudson's Bay where the port of Churchill has been established at the railhead.

The oceanography and fisheries of this region are being studied by the Atlantic Oceanographic Group and the Fisheries Research Board.

Off the Atlantic Coast of Canada, the cold currents flowing south from Greenland meet the warm Gulf Stream floating northward. This is one of the great fishing areas, and the world's most travelled sea route. It is bitterly cold in the winter, and sub-tropic in summer. Icebergs are frequent and dangerous. Oceanography in that area is concerned with the movements and properties of the water that affect the fisheries and ice movements.

The Atlantic Oceanographic Group, working with three ships, has explored the waters of the Gulf of St. Lawrence, the Scotian Shelf and Grand Banks, and northward into Davis Strait, Baffin Bay, Hudson's Strait, and Hudson's Bay. They have identified the water masses and currents, and are studying their seasonal and annual variations. This group carries out extensive oceanographic studies. Also it helps to plan the work of a number of contributing organizations, and to analyze the date. Every opportunity is taken to make use of Hydrographic Fisheries and Naval vessels in the area.

The ice in the Beaufort Sea and Western Arctic melts in June and the ice barrier retreats northward to latitude 75°N. However, the oceanography is such that great point of ice reaches south to Point Barrow in Alaska. This effectively keeps ships out of the area until the end of July, and closes the area early in September, even though the Beaufort Sea itself is open to navigation.

The Pacific Oceanographic Group and the U.S. Navy Electronics Laboratory have jointly explored this region each summer since 1949 and are developing the oceanography of this wind dominated, tideless sea.

The Canadian Archipelago is the barrier between East and West. Some of the greatest expeditions of discovery were lost here while seeking a Northwest Passage. The place names are cenotaphs of daring, hardship, and disaster. The ice melts slowly, and has very little freedom of movement in these shallow channels. Consequently the Northwest Passage has only been navigated a few times. The most notable achievements are the passages of the Royal Canadian Mounted Police vessel St. Roche commanded by Sergeant A. Larsen. They patrolled this region for twenty years, making five complete passages. Two years were

required for each trip and the ship was "frozen in" for the winter each time.

It has been said that there are a thousand ships in the Atlantic for every one in the Pacific. This is certainly true in the Pacific approaches to Canada. There is little or no trans-Pacific traffic. Fisheries and commerce are contained in the inland seaways, and within sight of land. The oceanographic explorations have been made by the Pacific Oceanographic Group, working with ships provided solely for this purpose by the Navy, the Hydrographic Service, and the Fisheries.

Thus the Pacific Group has had to devote most of its effort to observation.

The Pacific Coast of Canada is situated where the west-wind drift current (Japan Current) across the ocean divides, part going north to form the Alaska Gyral and part going south to form the California Current. The currents off the Canadian coast are slow (10 to 20 miles a day) and confused. There are considerable changes from year to year as the west-wind current shifts north or south exposing the region alternatively to Sub-Arctic or Sub-Tropic waters.

Five large synoptic surveys of this region were made in successive seasons from 1950 to 1952, and the oceanography has been described.

The Pacific Coast is also remarkable for the line of barrier islands, and the great runoff from the large rivers. There are a series of sounds, inlets, and straits. Each of these supports valuable local populations of salmon, herring, and other commercial fishes. Many of them are dominated by great tidal currents, and fresh water from the land. Each area is a complete oceanographic system, differing from its neighbors and from the ocean in many ways.

Each day at high tide a sample of sea water is taken at fifteen positions along the coast. The temperature is recorded, and the samples shipped to the base laboratory at Nanaimo, where the salinity is determined. These data are published annually and are widely used by fisheries, meteorologists, and shipping.

It has been found that these data define the seasonal cycles in the sea, mark the differences between regions along the coast, show the differences between years, and are generally an index of the oceanographic conditions. They have been correlated to the winds, the currents, and to the fisheries in Canadian and neighboring waters. They form a calendar of oceanography to which all other studies in the sea can be related. These daily seawater observations are one of the most important, and at the same time the cheapest of our oceanographic programs.

Exploratory surveys have been made in most of the seaways and the ocean. This is being followed by detailed studies in each region to determine their structure, and mechanism, and seasonal cycles of

changes. Surveys are made at weekly or monthly intervals throughout a year or so. The oceanographic state is related to the weather, the run-off, and to daily seawater observations. Thereafter, these readily observable characters are used as indices to recognize the oceanographic states, and in some cases to predict the conditions. The tedious and costly surveys are only carried on long enough to establish the relations with the daily observations. This is a very simple and effective plan which allows for the accumulation and use of oceanographic knowledge.

Juan de Fuca Strait is a broad (11 miles) deep (100 fathoms) channel connecting the ocean with the inland sea of Georgia Strait. It contains most of the shipping and the principal migration route of the salmon and herring. Here the tidal currents are reversing at all depths and are linear functions of the difference of tidal height between the ocean and Georgia Strait. The tidal wave progresses along the strait at about 30 knots, less than a fifth of the theoretical speed. The reasons for these effects have not been solved as yet. However, a system of prediction of the tidal currents at all depths has been worked out, and is as accurate as the normal weather variations will allow.

At the northern end of Georgia Strait the tidal flow through the narrow passages is purely hydraulic. At Seymour Narrows the currents attain thirteen knots, the fastest in the world, and are in effect two-way falls. Because of the great velocities there is a half-foot depression of mean sea level. Evidently mean sea level determinations should not be made in the vicinity of rapid currents.

Georgia Strait, Chatham Sound, and a number of the coastal inlets have been the subject of intense studies. These regions are dominated by the outflow of the major rivers. The fresh water flows out over the surface, mixing with the sea water as it goes. It forms an upper zone of brackish water which oscillates with the tide, but moves persistently seaward. The brackish water occurs as clouds which represent the river discharge during the falling tide. During the rising tide the sea water intrudes the estuary and stops the outflow. As the clouds move about in the vicinity of the river they become more saline and override earlier clouds, and so form multiple layers.

In all these systems the water tends to form layers in which the salinity varies as the logarithm of depth. The reason for this has not been determined. However, its occurrence has been established, and has been used to considerable advantage in analyzing the structure and origin of the waters.

Some progress has been made in the use of hydraulic models for the study of harbours, bays, inlets, and narrows. These are systems where the boundary conditions are known. We have just completed a study of Alberni Harbour. Tides are generated by the inflow of out-

flow of sea water, controlled by a four-component tide machine. Fresh water is discharged from the rivers, and forms an upper zone similar to that in nature. The model is studied by observing the salinity distribution, just as is done at sea, and by coloring the several water sources and making colored pictures of the model in action.

The model approach is cheaper and more satisfactory for the study of limited seaways than the conventional series of oceanographic observations. These two-fluid models are invaluable aids for defining the oceanographic structure and circulation in complex coastal seaways. They provide realistic data for sewage and pollution studies, and if they are not completely quantitative, they provide a good qualitative picture so that the oceanographer will know what to look for in the sea.

Applied oceanography is a considerable part of our research. The most important application, at present, is the disposal of domestic and industrial sewage and the control of pollution.

The city of Vancouver lies on a point of land between Burrard Inlet and the Fraser River. The city has grown to 500,000 people, and shows every evidence of growing to a million people in the next forty years. The Fraser River discharge oscillates with the tides but moves persistently northward around the foreshore. At the present time, the sewers discharge into the sea and the river all around the city. There are many excellent bathing beaches, but these are fouled by sewage, and will become worse as the city grows.

We studied the situation to find points of discharge where the sewage would be carried out into Georgia Strait, rather than along the beaches. Such a position was found, south of the North Arm of the river. From here the water is carried northward, outside the North Arm water. This solution has been accepted by the city, and the inhabitants are now consolidating their sewage disposal system in this site.

Similar sewage disposal problems have been solved at other coastal cities, and particularly at industrial sites. A number of pulp mills have been established in the province. Their waste discharges are toxic to fish unless quickly dispersed. It is the general practice for the oceanographers to examine the mill plans, especially the disposal system, and work with the industry to provide a safe discharge. This service is appreciated because it safeguards the fishery and relieves the mill owners of responsibility for pollution.

In our area oceanography is not regarded as a science in itself; rather it is a field in which the sciences are applied. Hence we have the application of the many phases of physics, chemistry, zoology, geology, and engineering in the ocean, in seaways, in rivers, and in lakes.

The Institute of Oceanography at the University of British Columbia provides post-graduate courses in physical, chemical, and biological oceanography leading to Master's and Doctor's degrees in each science. Research at the Institute is mostly concerned with fundamental problems in oceanographic processes such as mixing, internal waves, chemical activity of sea water, the relation of fishes to their environment, and the geological processes at work.

The National Organization that makes all this work possible is simple and economic. While Canada may be counted as one of the well-to-do nations, the resources for oceanographic research are definitely limited. This is a notoriously expensive field of study requiring ships, crews, costly equipment, and highly trained personnel. Prior to the war a large number of agencies dabbled in oceanography, but made little or no progress because they could not finance the work. However, after the war all the government departments that were concerned with oceanography pooled their efforts in the Canadian Joint Committee on Oceanography. The National Research Council, the Navy, the Defense Research Board, the Fisheries, the Hydrographic, and the Meteorological Services, are all members. Each contributes money or facilities, and the Atlantic Oceanographic Group (A.O.G.) or the Pacific Oceanographic Group (P.O.G.) carry out the research programs. The Oceanographic Committee of the Royal Society holds an annual symposium.

There are three oceanographic ships on the Pacific Coast, and four on the Atlantic. These are operated by the Navy, some with civilian crews, and some with Naval crews. Base Laboratories are provided by the Fisheries Research Board on each coast. Publication is provided in the Journal of the Fisheries Research Board, the Canadian Journal of Research, Proceedings of the Royal Society and a Manuscript Series from each Oceanographic Group.

In general, the Oceanographic Groups undertake all surveys and longterm observations, applied problems, and large fundamental problems. This consolidation is a great saving because it is often possible to satisfy several demands from the same set of data. For example, the daily seawater observations provide indices of submarine climate for the fisheries and an index of oceanographic conditions.

The arrangement has worked satisfactorily for eight years, and is gaining wider acceptance and support all the time.

INSTITUTE OF OCEANOGRAPHY, UNIVERSITY OF BRITISH COLUMBIA: Note on Work Since 1949 and Future Plans (By G. A. PICKARD)

The Institute of Oceanography of the University of British Columbia has decided to devote most of its effort to a study of oceanographic problems in the inlets of the B.C. coast. Before embarking upon a detailed study of any one inlet, the Institute carried out during the summers of 1951 and 1952 a survey of most of the major inlets in the B.C. mainland coast to extend the information then available. It is planned to extend the study to the inlets of the Queen Charlotte Islands in 1953.

Morphology of the Inlets.

The inlets vary in length from 5 to 90 miles, are ½ to 3 miles wide, and generally possess many abrupt bends. Only a few of the inlets had been sounded before the 1951 cruise and so observations of depth were made along the length of the inlets. The average depth is about 1100 feet (340 m.), depths of 1800 feet (550 m.) are common, and the maximum is about 2400 feet (740 m.). In some cases the bottoms are regular but in the majority of cases considerable irregularities are observed. Only two inlets have marked sills 150 feet (45 m.) while no very shallow sills such as occurring in the Norwegian fjords are known. The most typical transverse section has the form of a truncated V, the rocky sides of the inlets having slopes as steep as 45° while the mud bottom is flat and level within the accuracy of a competent hydrographic survey.

Bottom Sediments.

The predominant material is a finely divided grey mud. 93% of the bottom samples taken in the survey contained mud, 22% contained some sand and only 12% contained pebbles. Only 2 in 73 samples smelled perceptibly of H_2S.

The bottom samples from Bute Inlet have been examined in detail and are found to be predominantly silts with the sand fraction never exceeding 5% except in areas off the mouths of inflowing rivers where the sand fraction may be as much as 25%. The sediments are dark grey when wet and light grey when dry. Quarts, feldspar and mica are the predominant minerals. The organic content is less than 1% and the calcium carbonate less than 1%. Diatoms are abundant and foraminifera and sponges are evident near the mouth of the Inlet.

Water Structure.

It is apparent that, with one possible exception, all the inlets are estuaries in the current oceanographic sense of the word in that the sea

water in them is appreciably diluted with fresh water in the upper layers. This fresh water comes from the rivers, mostly glacial in origin, which empty into the heads of almost all the inlets, and it is the lack of such a river which distinguishes the upper 10 miles of Belize Inlet from the remainder. This is the only region in which there was any evidence, in the form of oxygen depletion, of stagnation.

The depth of the mixing layer between fresher surface water and deeper saline water varies from 3 to 10 meters in different inlets and in some cases varies somewhat in depth along individual inlets. There is ample evidence in the drift of the vessel, and from current measurements, of the outward flow of the surface water. In many cases there is a very marked velocity shear in the mixing layer, the major part of the change in velocity taking place in as little as ½ to 1 meter. At the heads of the inlets the fresh water forms a sharply defined layer over the saline water but the mixing which occurs along the length of the inlet results in a more gradual change of salinity with depth toward the mouth of the inlets. It appears that the change from the two-layer system to the continuous distribution takes place to the same extent irrespective of the length of the inlet—the significance of this fact is not yet fully understood.

The greater part of the fresh water resides in the top 20 m. of the water and below about 30–50 m. Each inlet shows only a slight change with depth or with longitudinal character.

In the summer the temperature of the upper water is increased above that of the deeper water by solar radiation but rarely rises above 17°C, while the deeper water temperature lies between 5.5° and 7.5°C.

The deep water in the southern inlets (south of Knight Inlet) averages about 30% salinity and 7.5°C temperature while the corresponding values for the northern inlets are 32.5% and 6.5°C.

A feature of the vertical temperature distribution, not previously reported, is a temperature minimum, at intermediate depths, which varies in character during the year. In several of the inlets the temperature passes through a minimum value at 50–60 m. depth, increases to a maximum at 60 to 100 m. and then decreases slowly to the bottom. The water in the minimum temperature layer is colder but slightly less saline than the deeper water. In Bute Inlet, where this feature has been studied in most detail, it is found that this low temperature layer comes into existence suddenly about February and gradually dissipates until it becomes indistinguishable by the end of the year. It is at present thought that this layer results from the cooling of surface water during the period of lowest air temperature when the salinity is at its highest

but there are still some features which suggest that this may not be complete explanation.

Internal Waves.

Another characteristic of the B.C. inlets not previously described is the existence of marked internal waves both at mid-depths and also near the surface. The mid-depth internal waves have been observed in most detail in the region of the temperature minimum at depths between 50 and 150 meters in series of bathythermograms made for periods up to 70 hours. They have periods of approximately 12 or 24 hours and amplitudes up to 20 m., but it is as yet uncertain whether these waves are progressive or standing in character.

The most marked shallow internal waves have been observed in Knight and Observatory Inlets in the boundary between the brackish surface water and the deeper saline water. The depths of the boundaries at the time were 5 and 8 m. respectively and the internal waves had amplitudes as great as 8 m. and periods from 1.3 to 2.6 minutes. These shallow internal waves are observed in the vicinity of the sills in these inlets when the tide is turning to the flood. It is believed that they are a consequence of instability in the flow associated with the considerable velocity shear which exists at this time.

Velocity Structure.

A start had been made in obtaining vertical velocity profiles in some of the inlets. The depth (650 m. or more) makes anchoring difficult but some preliminary results have been obtained. These confirm the outward flow in the brackish layer, with up-inlet flow below this, and considerable shear in the region of the halocline. Unfortunately the tidal currents are superposed upon the estuarial flow and since their detailed distribution with depth is not at all well understood, it has not yet been possible to separate the estuarial components alone.

Zoological Collections.

During the 1951 survey trawling was carried out in shallow waters in many inlets, while plankton hauls were made at regular intervals. Over 1100 fish of 55 species representing 19 families were taken, cottids (sculpins) and peuronectids (soles) being most common. No species not previously reported in B.C. waters were taken but a number of uncommon ones were observed and an extension in range of several varieties was noted.

Both phytoplankton and zooplankton collections were made but only the latter have yet been examined. The total settling volume of

plankton per cubic meter of water varied from 0.01 to 55 cc. while the zooplankton volumes averaged between 0.5 and 1 cc. A preliminary examination of the individual samples indicates definite species differences with depth, position in an inlet, and from inlet to inlet, and an attempt is being made to correlate the distribution with temperature and salinity. The most abundant groups were Copepoda and Cladocera, which often occurred in complementary proportions. The former were more abundant in the deeper (and usually more saline) water, whereas the latter were more common in the upper layer of less saline water. The Cladocera were often the only zooplankton present in the upper, brackish water.

Future Policy.

The immediate aim of the Institute's field observation programme is to obtain more detailed information about the current distributions, both in depth and transversely, with the object of separating the tidal and estuarial components. Further observations of the mid-depth internal waves are planned in order to determine their frequency and whether they are progressive or stationary.

A study of the plankton populations is also being made in order to determine if there are any correlations with the circulation.

Cameron (1951) has demonstrated the relationship between the mass and velocity distributions in a deep inlet. He has introduced into the equations of motion in a two-dimensional tideless mathematical model, and analytical expression of the presumed transport and derived a mass field which is similar to that observed in typical B.C. inlets.

He has presumed eddy frictional force proportional to the vertical gradual of shear, and retaining the vertical terms, has indicated the existence of a critical transport in the steady state. The soleaoidal field resulting from the fresh water distribution is sufficient to maintain a steady state of field acceleration and balance frictional forces similar in magnitude to those derived by Jacobsen.

He is continuing his investigation into the possible effect of tides in such an inlet. There is evidence to suggest that their dynamics may contribute to the maintenance of an average baroclinic field and that the present concept of the role of eddy forces may be exaggerated.

The Institute has supervised the analysis of hydrographic and oceanographic data obtained in the southeastern Beaufort Sea in 1951 and 1952. Cameron has reported (1951, 1952) that the influence of the MacKenzie river on the circulation of the contiguous inshore waters is predominately to the east of the MacKenzie delta. He has demonstrated the important effect of winds on the distribution of the freshwater discharged by the river.

McAllister (1953) has reported that the distribution of surface plankton in the southeastern Beaufort Sea reflects the physical oceanographic features of the area. His analysis indicates that the productivity of the region is significantly lower than that of the Chutchi Sea.

BRIEF REPORT ON OCEANOGRAPHICAL RESEARCHES IN CHINA

By Chu Tsu-Yao

Before World War II there were many people in universities who studied Marine Biology. Some papers were published. Some meteorological observatories took observations of water temperature and salinity of the coastal waters. These research works have been interrupted since the beginning of the war. Now, in Taiwan, we carry on research work in different phases of Oceanography. For example Dr. Ma, who is a geologist in the Taiwan University, studies the topography of the sea bottom, coral reefs, etc. Mr. Ko, who is a zoologist in the Teacher's College of Taiwan Province, studies the economic fishes in the district of Taiwan. The Research Laboratory of the Fisheries Rehabilitation Administration and the Fisheries Institute of Taiwan Province make studies both on biological and physical oceanography. Besides, the Taiwan Weather Bureau maintains fine stations on the coast in which we take observations of water temperature and salinity regularly. We are planning to establish a research Center on fisheries and oceanography hoping to unite all the people concerned in one organization. Perhaps we can get some aids from the MSA mission to China. Research work in Oceanography is expensive and China financially still is not very stable. Owing to the shortage of funds and lack of technical experts, some difficulties may be encountered. We will do our best to overcome all these difficulties in the hope of making progress step by step. We also hope to participate in all activities in cooperation with other countries in research work in the oceanography of the Pacific.

OCEANOGRAPHY IN INDIA

By N. K. Panikkar

It cannot be said that oceanographical research work is receiving active attention in India, although a great deal of preliminary effort is being made to organize research on the various problems. What little

work is being done is with a strong bias to biological and fisheries topics. Plans are afoot, however, for the eventual setting up of an Institute of Oceanography to cover both biological and physical-chemical aspects.

During the British administration, considerable amount of oceanographic work was carried out by Col. R. B. S. Sewell while he was Surgeon Naturalist to the Government of India and later on Director of the Zoological Survey of India. He studied the temperature and salinity of the waters around India down to 500 fathoms depth and the results were published in a series of papers. During the "John Murray" Expedition which was led by Sewell, an attempt was made to carry out a complete investigation of the physio-chemical characters of the sea water as well as of the fauna and the general topography of the Arabian Sea and Gulf of Oman. After the country attained independence, more attention is being paid to oceanographic research and a beginning is being made in sponsoring work relating to this through the various governmental agencies and universities.

In view of the great importance attached to Geophysical problems, the Government of India constituted the Central Board of Geophysics early in 1949 and a special committee for Oceanography has also been set up by this body. One of the chief centres where oceanographic work is initiated is the Central Marine Fisheries Research Station, Mandapam (S. India).

The oceanographic studies carried out in the Central Marine Fisheries Research Station are with a definite bias to the development of fisheries, although a certain amount of pure scientific studies is undertaken for a complete understanding of the marine environment supporting the fisheries. Attention is centered around chemical and biological aspects at present. The fluctuations in the nutrient salts, oxygen, salinity, temperature variations, etc. in the inshore waters; bacterial flora and their role in the food chain of the sea; qualitative and semi-quantitative study of the phyto- and zoo-plankton, their distribution and their variations in time and space, bottom fauna, etc., some of the organic production in the waters around India, have been started. As a result of collaboration with the Indian Naval Vessels patrolling coastal waters, it was possible for the Station to collect hydrological data (temperature, salinity and pH) at about 25 stations in the Bay of Bengal and readings were also taken with the Bathythermograph of the temperature at different depths. Very interesting results on the thermoclines at the head of the Bay of Bengal have been obtained. A scheme for the collection of water samples from areas traversed by Indian Naval Vessels is already in existence, by which Naval Vessels send to

the Central Marine Fisheries Research Station water samples collected from various localities with details of temperature and exact location of stations from where samples are collected, and these samples are subsequently analyzed. A further extension in the collection of water samples through the Merchant Naval Vessels is at present under consideration.

Some work is also being carried on by the Indian Meteorological Department particularly relating to turbulence and microseismic waves. The survey of India maintains continuous tidal recording stations in all major ports. The Indian Navy has a research laboratory at Cochin, on the west coast, where research on underwater sound and oceanography is undertaken. They are now in the process of setting up a wave recorder and are also studying the vertical thermal structure of the sea. Future plans also call for seismic studies of the sea floor. The survey ship INS "Investigator" conducts hydrographic investigation along the extensive 2900-mile coast of India.

The teaching of oceanography is carried on at Andhra University, Waltair; physical oceanography in the Geophysics Department, marine Geology and marine Zoology in the Geology and Zoology Departments, respectively. The University is conveniently located on the central part of the east coast adjacent to an excellent harbour, Visakhapatnam. Cruises have been made out of Visakhapatnam along the east coast between Calcutta and Madras, and one extending around the southern tip of India to Cochin. On these cruises students are trained in the especially interesting, primarily because the currents are completely reversed when one monsoon is replaced by the other. There is great dilution from the enormous rivers; the submarine canyon "Swatch of no Ground," probably sets forth turbidity currents; and upwelling and sinking appear to be present at different seasons. Recently work on these lines has been initiated by a visiting scientist, Prof. E. C. la Fond, from the U.S.A.

PHYSICAL OCEANOGRAPHY IN JAPAN IN THE PERIOD 1949–53

By Koji Hidaka

1. Introduction

This is the report on the activities in physical oceanography in Japan for the years 1949–1953, or since the Seventh Pacific Science Con-

gress was held in New Zealand in 1949. A summary of the activities in the universities, institutions and government organizations will be reviewed.

2. Oceanographic Observations in Japan during the Period 1949–53

Oceanographic observations in our adjacent seas are now being carried out very frequently, with the surveying ships of the Hydrographic Office, Maritime Safety Agency, Tokyo, Seven Fisheries Research Laboratories, and the Central Meteorological Observatory, Tokyo, including its four subordinate marine observatories, and some local agencies subordinate to them. The elements observed range over almost all branches of physical, chemical, biological and geological oceanography. The activities were no doubt interrupted by World War II, but they are now getting rapidly recovered. Still the facilities and the apparatuses are so inadequate that the observations are mostly confined to the layer shallower than 1000 to 1500 meters. We imported bathythermographs, and many ships now are equipped with lorans and radars. Still we do not have a great number of observations in all layers from the surface down to the ocean floors. At the same time it is desired that the instantaneous states of the oceanic phenomena should be caught with great accuracies.

The above organizations responsible for oceanographic research are divided into three groups, namely:

1) The Hydrographic Office, Maritime Safety Agency, Tokyo.
2) The Tokyo and six other Fisheries Research Laboratories, distributed over this country.
3) The Meteorological Observatory, Tokyo, and subordinate Marine Observatories at Hakodate, Kobe, Maizuru and Nagasaki, and some coastal meteorological stations.

The Hydrographic Office, Maritime Safety Agency, which celebrated its 80th anniversary in 1951, has been carrying out hydrographic observations once to three times a month with the Surveying ships "Kaiyo" No. 4 and "Kaiyo" No. 5 and "Tenkai No. 1," the explored areas being seas around Kyushu, seas to the south, southeast and northeast of Honshu, a part of Japan Sea, seas around Hokkaido, etc. In September 1952, they lost "Kaiyo No. 5" by a submarine eruption to the south of Japanese Island. (M. Nakano KH, 2, 1952).

Current measurements continuing for 15 days were carried out at the central part of the Hirado Straits, Kyushu, during July and August 1948, in the Shimabara Kaiwan, Kyushu, during the period July to September 1949, and in the Yatsushiro Sea, Kyushu, during the period July to August 1950. The number of current stations where the measurements continued for one day amounts to 61 in 1948, 39 in 1949 and

127 in 1950. Special observations where the measurements continuing for less than one day have been made at many stations. This organization is now directed by Dr. Kanji Suda, and Terutoshi Nakamiya takes charge of the Hydrographic survey.

In 1949, the governmental fisheries organizations were divided into seven Research Laboratories. Tokyo Fisheries Research Laboratories, now directed by Dr. Gensho, has carried out monthly observations between Tokyo and Hachijo Island with the M.S. "Soyo Maru" and "Tenyo Maru". Stresses are laid upon the research of sardine resources in the Pacific. In 1951 the Nankai Regional Fisheries Research Laboratory made observations in the tuna fishing grounds in the Equatorial Pacific in close cooperation with the Pacific Ocean Fisheries Investigations in Hawaii. There have been additional oceanographic observations in Tohoku areas (off Northern Honshu, June 1949), in the areas from Tokyo to the western sea of Kyushu for 65 days from February to April 1949 with the "Soyo Maru" for the investigation of sardine spawning and oceanographic observations, in the same area for 70 days from February to April 1950 with "Tenyo Maru" for the same objects in the waters to the northwestern part of Kyushu and the Tsushima Straits on 1–4 March 1950, in the area to the south of Shikoku and Honshu in the middle of March 1950, on the profile from Nozima Zaki to the point 1°N and 147°E. During the period from June to August with the "Taiyo Maru No. 1", the area to the south of Japan (from Tateyama to a point 1°N 150° 20′E) with the "Tenyo Maru." During the period from June to August with the "Taiyo" graphic observations were made in the fishing grounds of salmon near the Aleutian Islands. They have a program to carry out the observations in the Tsushima Current area in the Japan Sea.

Other five Research Laboratories do not show special activities at present, except the observations in the Japan Sea carried out by the Japan Sea Fisheries Research Laboratory recently.

The training ships "Umitaka Maru", "Shunkotsu Maru", "Shinyo Maru", and "Seicho Maru" of the Tokyo Fisheries University have been engaged in the oceanographic cruises for the survey of the Kuroshio region and geological research of the sea floors.

The Division of Oceanography, of the Central Meteorological Observatory, Tokyo, has sent M.S. "Asashio Maru" on about five cruises every year chiefly in Sagami Bay, carrying out regular oceanographic observations. Surface observations were made on board the liners between Tokyo and Hachijo Island about three times a month. This division has been directed by Dr. Mashito Nakano until recently. They made 15 cruises in the Sagami Bay areas and occupied 174 stations dur-

ing the period 1949-53, including regular hydrographic observations, observations of diurnal variations of several oceanographic elements, observations in the estuaries. They have carried out four regular cruises in Tokyo Bay during the period 1949–52 and occupied twelve stations in each cruise, some of them involving measurement of internal waves, and the test of self-recording current meter devised by T. Nan'niti.

The observations in the Kuroshio area were made in two cruises in the area south of Tokyo during 1952. Twenty stations have been occupied in these cruises. Weathership Observations were made by other divisions on board "Ryohu Maru", "Ukuru Maru", "Chikubu Maru", "Shinnan Maru", and "Ikuna Maru", at the St. X (39°N 153°E) all the year round, and at St. T (29°N 135°E) in summer months. Oceanographic observations were made on their courses to and from the weather ship stations.

Hakodate Marine Observatory, Hakodate, directed by Dr. Yoshitada Takenouti, has made the oceanographic observations on board the "Yushio Maru" every month. The exploring areas are chiefly the seas to the NE of Japan, and sometimes off Hokkaido, the northern part of Japan Sea, etc. The surface observations were made in the Tsugaru Straits on board the liners three times a month.

Maizuru Marine Observatory, Maizuru, directed by Hideo Kawasaki, has made observations on board the "Kuroshio Maru" in Wakasa Bay, Maizuru Bay, and surrounding areas about three times a month since November 1949.

Kobe Marine Observatory, Kobe, directed by Dr. Yasuo Matsundaira, has made the oceanographic observations in Osaka Bay, Kii Suido, etc., with the M.S. "Shunpu Maru". In addition current observations have been carried out.

Nagasaki Marine Observatory, Nagasaki, directed by Dr. Kazuhiko Terada, has carried out the oceanographic observations in the adjacent seas with the Research Ship "Umikaze Maru" and surface observations have been made on board the liners connecting Nagasaki and the Goto Islands. Special attention has been paid to the observation in the areas west of Kyushu including the shallow areas bordered by numerous islets in the regions. They are also planning to observe the seiches or stationary oscillations in Nagasaki Harbor which sometimes cause damages to the shore with the enormous amplitudes. This observatory is also active in the forecasting of the wind waves and the meteorological tides.

There are several coastal meteorological observatories which have surveying ships. M.S. "Koshi Maru" of the Niigata Local Meteorological Observatory, M.S. "Oyashio Maru" of the Hachinohe Meteorological Observatory, etc., have made the oceanographic observations offshore.

In their voyages to the Antarctic whaling grounds oceanographic observations have been made on board the Japanese fleet of whalers by the members of the meteorological agencies.

3. Three-Agency Marine Research Coordination Council

Three government agencies, the Hydrographic Office, Maritime Safety Agency, Fisheries Research Laboratories, and the Meteorological Agencies meet in negotiations about three times every year in order to coordinate the mutual understanding and cooperation, and the representative members from each agency showing one another their results of observations and expeditions after the preceding meeting, and conferring about the plans and areas to be explored by each agency in the subsequent period so that they may not be superposed one upon the other.

4. National Committee on Geophysics, Section of Physical Oceanography

This is a committee established in Japan to keep sound liaison with the International Union of Geodesy and Geophysics. The Section of Physical Oceanography has about 13 members; Dr. Koji Hidaka is the chairman and Dr. Yasuo Miyake is the secretary.

A sub-committee has been appointed in this section on the preparation of standard sea water, under Dr. Yasuo Miyake, chairman. Since the administration of the Standard Sea Water must be international, it is agreed within home oceanographers that this sub-committee should be dismissed as soon as the international standards become available in this country. It was only in 1952 that we could have Copenhagen water in Japan.

There is the Special Committee for Marine Resources in the Commission for UNESCO, Science Council of Japan, and Dr. M. Ishibashi is now the chairman.

5. The Oceanographical Society of Japan

This scientific society was established in January 1941 under Dr. Takematsu Okada as the president. It has issued a popular monthly journal "Kaiyo no Kagaku" (Science of the Sea) and the Journal of the Oceanographical Society of Japan (quarterly, purely scientific), both in the Japanese language, and recently it recommended to publish papers in English in the journal. The president is now Dr. Koji Hidaka. "Kaiyo no Kagaku" has not been issued since 1951.

6. Pacific Science Investigations

Dr. Shinkishi Hatai, who has long worked as the member for Japan in the Pacific Science Council, resigned in 1950 from this position and

Dr. Koji Hidaka succeeded him. However, Hatai is still very active as the chairman of the Pacific Science Committee, Science Council of Japan, with about thirty members. Hidaka is also acting as the general manager of this committee.

In 1950, Hatai planned to create a certain research group to carry out the oceanographic survey of a certain definite area similar to the Palau Tropical Laboratory, West Caroline Islands, of which he had been the director until the end of the war. He looked for an area located in the southernmost part of Japan at that time and after long discussions with collaborators, he chose the Hachijo Island about 33°N and due south of Tokyo. A systematic study was begun in 1951 from all fields in oceanography around this small island. A very active cooperation is being made since that time in this area. He issued a second report on the research in the area early in 1953.

Close cooperation with the Pacific Science Council Secretariat is being made, too. K. Hidaka contributed to the Pacific Science Council Secretariat by sending the materials concerning the expeditions carried out by the Japanese in the Pacific area in the past 70 years.

In 1952, K. Hidaka, M. Uda and Y. Hiyame, all members of the Pacific Science Committee were appointed members of the Physical Oceanography and Marine Biology Panel sponsored by UNESCO. (UNESCO/NS/105, Paris le 5 fevrier 1953; Original: anglais-francais.)

7. Publications

At present the following publications of oceanographical interest are issued from the institutions and societies in Japan.

The Tokyo Fisheries Research Laboratories, Oceanographical Division

(1) Kaiyo-zu (Oceanographical Charts, chiefly for fisheries workers, in Japanese) reports the distribution of temperature and salinity three times a month.

(2) Kaiyo Tyose Yoho (The Oceanographical Observations): List of oceanographic data obtained by all fisheries agencies.

(3) Suisan Kenkyujo Gyoseki Shu (Contributions from the Fisheries Research Laboratories), 1950.

The Hydrographic Office, the Maritime Safety Agency, Tokyo

(1) Suiro Yoho (Hydrographic Bulletin, in Japanese): bi-monthly, contains mainly quick information on the observational data in hydrography and related topics.

(2) Kaisho Iho (The Oceanographic Bulletin): Irregular, contains the results of observations and miscellaneous, 1947–50; publication suspended from May, 1950.

The Central Meteorological Observatory, Tokyo (CMO), Division of Oceanography

(1) Kaikyo Gaiho (Preliminary Report on the States of the Seas adjacent to Japan, in Japanese). Three times a month, 1946.

(2) Kaiyo Hokoku (Oceanographical Report of CMO, in Japanese) 1 (1) 1949.

(3) The Oceanographical Magazine (quarterly, in English and other foreign languages), 1 (1949), 2 (1950), 3 (1951, 4 (1952) 5 (1953): This contains papers on oceanography and marine meteorology.

(4) Nippon Kinkai Kaikyo Gaiyo (in Japanese) reports the general hydrographic conditions in the seas adjacent to Japan as derived from the observations during past one year, 1949.

The Kobe Marine Observatory

(1) Papers and Reports in Oceanography (in English), Nos. 1–4 1949), No. 5 (1950).

(2) Kaisho Geppo (Monthly Report on the Hydrography in the Adjacent Seas of Japan, in Japanese) reports the data observed in the seas and along the coasts and other various oceanographical phenomena, 1950.

(3) Memoirs of the Kobe Marine Observatory (in English), being a continuation of the Memoirs of the Imperial Marine Observatory.

(4) Choseki Hokuku (Tidal Observations), 1950.

(5) Kiyo Ziho (Journal of Oceanography, in Japanese), irregular at present.

The Mizuru Marine Observatory

(1) Oceanographical Reports (in English).

(2) Kikyo Gaiho (General Hydrographic Bulletins, in Japanese).

(3) Kiyo Kisho Kansoku Hokoku (Reports on Marine Meteorological Observations, in Japanese).

The Nagasaki Marine Observatory

(1) Kaisho to Kisho (Oceanography and Meteorology, in Japanese), 1 (1947)–5 (1951).

(2) Kaikyo Ryakuho (Journal of Oceanography, in Japanese), 1947–1949: continued by "Kaiyo Kansoku Hokoku" (Reports of Oceanographical Observations, in Japanese).

(3) Nishi Nippon Kaikyo Zyumpo (Western Japan Hydrographical Bulletin, in Japanese), three times a month.

(4) Nagasaki Kaiyo Kisyo Kai Hokoku (Report of the Nagasaki Marine Observatory, in Japanese and in English), 1 (1948)–3 (1950).

The Hokodate Marine Observatory

(1) Kaiyo Ziho (Journal of Oceanography, in Japanese), irregular at present.

The Oceanographic Society of Japan, Tokyo

(1) Journal (quarterly, scientific papers in Japanese, English, and other languages).

(2) Kaiyo no Kagaku (Science of the Sea), monthly, popular magazine, now suspended for financial reasons.

Kaiyo Kisho Gakkai (The Marine Meteorological Society), Kobe

(1) Umi to Sora (Seas and Sky, in Japanese) chiefly contains papers on oceanography, meteorology and geophysics.

Science Council of Japan, Ueno Park, Tokyo

(1) Records of Oceanographic Works in Japan. New Series, (Vol. 1, No. 1, March 1953), being the continuation of a publication of the same name; Vol. 12, No. 2, issued before World War II.

Geophysical Institute, Tokyo University, Tokyo

(1) Geophysical Notes and Collected Oceanographical Papers.

8. Personal Activities

In the following lines brief descriptions will be given on the personal activities in all fields of physical oceanography. These have been enabled by a friendly cooperation of the individual research worker by informing me of the results of his work in this period. I hereby express my deepest thanks to these authors for their kind cooperation.

Sea Water

During World War II, Japan was obliged to prepare the standard sea water herself for titrating the salinity. After the end of hostilities this was sent to the Scripps Institution of Oceanography, and the Department of Oceanography, University of Washington, for comparison; and it was found that our standard sea water did not differ by more than $/0.02^{0}/_{00}$ Cl compared with the Copenhagen water. The preparation has been sponsored chiefly by Y. Miyake, chairman of a committee especially appointed for this purpose (GM, 20, 1949, 101-104). Miyake and Katsuko Saruhashi planned to devise a microtitration of chlorinity. They made a micro-pipette of 1.5 cc. content and a micro-burette graduated to 0.001 cc. and used a silver nitrate solution

of the same concentration as in ordinary Knudsen-Mohr's method. As the absorption indicator, sodium fluorescenate is used. They are intending to save both time and expenses without losing accuracy (in press).

K. Hishida applied Einstein's formula in order to find out the direct influence of the chlorine in the sea water upon the turbidity, and found that practically it does not affect the turbidity for the variation of salinity usually found in the sea (OM, 3, 1951, 103).

In 1952, Miyake completed the calculation of the saturated vapor pressure of sea water for the range of temperature from—2°C to 40°C at 0.1°C interval and that of chlorinity from $1^0/_{00}$ to $22^0/_{00}$ at $1^0/_{00}$ interval (GM, 4, 1952, 95–118).

Miyake and his collaborators have long been engaged in the study of the formation of the bubbles in sea water. Miyake tried to find out the possibility and allowable limit of an air bubble formation in the sea and a formula was obtained for the saturation amount of dissolved air in sea water. Since bubble formation in the sea water depends on the pressure *in situ,* new concepts, the saturation amount *in situ* and the saturation percentage *in situ* are introduced. Possible causes for bubble formation were discussed and a graphical method is given to compute the depth and the quantity of air to be evolved (MGP, 2, 1951, 95–101).

T. Abe, one of his collaborators, studied the thickness of the bubble layer, that is, the layer in which the bubbles are formed in the test tube by shaking it by hand. He found that this thickness increases slightly with temperature and exponentially with Cl, and that bubbles are hardly seen in inorganic salt solutions (in press).

K. Saruhashi, one of Miyake's collaborators, applied Conway's micro-diffusion method to the analysis of the total carbon dioxide in the sea water. She deduced a theoretical relation between pH and the total carbon dioxide in sea water (MGP, 3, 1953, 202–206).

In the diurnal variation of dissolved oxygen in surface water, the maximum occurs at about 4 P.M. and the minimum at 6 A.M. or so. The difference between the maximum and minimum is dependent on the solar radiation, temperature and the amount of phytoplankton. Y. Sugiura obtained a formula giving the amount of dissolved oxygen, in which the yield of oxygen were taken into account. The results of calculation agreed fairly well with observations (in press).

Miyake, Sugiura, and K. Kameda made observations of chemical elements in the sea water around Hachijo Island in July, 1951, and in December, 1952. A marked inverse correlation between chlorinity and silicate content was noticed. Chemical analysis gave the result that the

effect of inland water can be seen in the region several kilometers off this island (ROWJ, 1, 1953).

Energy Exchange Between the Sea and Atmosphere

In 1949 Michio Miyazaki made an attempt to estimate the heat budget in the Tsushima Current flowing along the Japanese coast of the Japan Sea. He assumed that the gain and loss of heat per day at the sea surface in this warm current can be calculated by the balance of incoming solar radiation, radiation from the earth, evaporation and cooling by convection. He obtained the results that the net loss of heat from the sea surface by terrestrial radiation is nearly constant throughout the year, that the rate of evaporation and the cooling by convection is greater in winter and smaller in summer and that the annual net gain by the sea is negative, showing that the heat is transported by the current (OM, 1, 1949, 103–111). He also applied the same computation to the entire Japan Sea, dividing this sea into 2-degree squares, and discussed the heat budget, formation of water masses, transportation of heat by currents (HFLB, 4, 1952, 1–54). A similar attempt was made by K. Terada and T. Osawa for some areas in the adjacent seas of Japan (GM, 24, 1953, 155–170). T. Ichiye also showed that the annual thermal cycle in the Osakawan cannot be explained by the evaporation and radiation from the water inside the bay, but that we must take into account the heat entering from outside the bay by horizontal diffusion (JOSJ, 6, 1950).

A similar estimate of the heat exchange between the atmosphere and the sea was made by J. Masuzawa based on the weather ship observations at a station 29°N, 135°E (OM 4, 1952, 49–55).

M. Hanzawa followed Sverdrup and Jacobs in estimating the evaporation from the sea surface based on weather ship observations at two stations close to the Japanese Islands. He found that in the North Pacific the maximum evaporation takes place in winter months and it is in a minimum in early summer. He compared the result with G. Wust's (OM, 2, 1950, 77–82).

Oceanographic Optics

Since several years ago T. Takenouti has studied submarine illumination in seas and lakes. He defined as "diffusion-ratio" the ratio of the illumination by the light from above over that coming from below. He showed theoretically that this ratio is independent of the depth of the layer if the water is optically uniform and only varies when there is a stratification of layers. He compared this with actual observations successfully. He found that hitherto debated variation in the characteristics of this layer has all depended on the discontinuous layer

present in a shallower level. He mentions this trouble is partly due to the difficulty in locating this discontinuous layer by simply measuring the submarine illumination (OM, 1, 1949, 43–47). He also studied the optical significance of the transparency measured by Secchi's disc. He concludes that the transparency of sea water should be defined as the depth at which we cannot distinguish the difference in colors of the disc with the surrounding water, in addition to the difference of illumination (OM, 4, 1950, 129–136). He also pointed out that the extinction coefficient is a constant peculiar to sea water, independent of the altitude of the sun and amount of clouds. He determined the relation between extinction coefficient and wave length of light and obtained a standard value of extinction coefficient for each of Forel's scales of color of the sea. He divided the extinction coefficient of sea water into the absorption and scattering coefficients. According to his observations with a photometer of photoronic cell type, scattering coefficient occupies only 10% of the extinction coefficient. This fact requested him to assume the existence of a colored substance in sea water. He determined the relation of transparency and extinction coefficient and showed that the formula at Atkins and Poole only holds for small value of transparency. This conclusion agrees with observations very closely (KJ, 4, 1952, 268–324). K. Hishida also made a photometer of the photoronic type and found that the submarine illumination has much to do with the hydrography (MMOR, 2, 1951, 21).

A theory of transparency of sea water was propounded also by T. Nan'niti, who derived a theoretical relation between transparency and hydrographic factors (MGP, 3, 1953, 195–201).

Annual variation and correlation between color of the sea, transparency and the plankton volume were studied by M. Koizumi. He found that there are two maxima in the color and transparency of the sea, that is, in summer and winter and two minima in spring and fall, and that this variation reflects the seasonal change of plankton volume which reaches a maximum in spring and a secondary maximum in the fall. From this result a simple formula was obtained between them (JOSJ, 8, 1952, 79–83).

Sea Ice

The intense studies on the sea ice in the areas around Hokkaido, the northernmost island of Japan, have been made by K. Fukutomi and his colleagues, K. Kusunoki, T. Tabata, T. Kashima, M. Saito, U. Kudo, and others. They are published in the Japanese language in 18 papers entitled "Studies on Sea Ice" during the period 1949–52 (TK, 3–9, 1950–52). Kusunoki compiled a bibliography of Sea Ice in Japan and made a list of references dated from 1892 to 1950 (JSSI, 13, 1952).

Fukutomi made extensive studies on the formation and growth of the ice crystals in sea ice, salinity and physical measurement of strength, microscopic inspection of the structure of sea ice, prediction and the growth of ice in the central part of the Okhotsk Sea. He also found that there is a turbulent layer of about 40 m. thick on the surface of the Okhotsk Sea. He established a theory of formation and growth of sea ice and applied it to this area and could predict when the ice is formed in this area, and how it grows. He also tried to estimate by simple empirical formulas the dates at which the air temperature over the sea reaches the freezing point of sea water. He made an extensive survey of ice along the north coasts of Hokkaido Island and discussed how the temperature distribution varies with the cycle of the atmospheric temperature, and compared the result with theory. He measured the temperature and salinity *in situ,* and concluded that off the northern coast of Hokkaido there exists a supercooling in the sea water just below the lower surface of the ice. Fukutomi, Kusunoki, and Tabata examined the wind drift of ice and recognized the influence of the Earth's rotation showing a deviation from the direction of the wind. They made experiments with a floating block of ice in a narrow sea and applied the result on the ice drift off the northern coast of Hokkaido. They also discussed theoretically how the stationary motion of ice occurs when the surface of the sea is partially covered and compared the result with those obtained by Nansen in the Arctic Sea during the drift of the "Fram" in 1893–96. Fukutomi and Kusunoki also published a theory on the formation and structure of ice ridges. Fukutomi, Saito and Kudo measured various physical properties and structure of the sea ice by photographic methods. Fukutomi gave a theory for the approximate estimates of the thickness of sea ice in relation to the average air temperature, and its annual range. Tabata tried a prediction of the data at which a last tract of drift-ice can be seen in the southern Okhotsk Sea coast of Hokkaido (TK, 3–9, 1950).

Hydrography

The hydrography of the East China Sea was discussed by M. Uda and he made clear the seasonal variation of water temperature, salinity and meteorological factors in the Yellow Sea and the East China Sea, and showed that the fluctuation of the Kuroshio at the margin of the continental shelf controls the intensity of the Tsushima Current. (Report of the Seikaiku Regional Fisheries Laboratory, 1950). He also discussed the hydrographic fluctuations in the Japan Sea (Japan Sea Regional Fisheries Laboratory Report, 1952).

Hydrography in the Japan Sea during the spring and summer, 1949, has been reported by I. Yamanaka (JOSJ, 6, 1951; 1953, in press).

Hydrography of the northwestern part of Hokkaido in 1949 was reported by K. Fukutomi and others (A Survey of Deep Sea Fish in Northern Part of Japan Sea, 1950), of the region south of the Kurile Islands and the southern part of Okhotsk Sea, by T. Tabata (TK, 10, 1952), of the northern and middle Okhotsk Sea in summer, 1942, by K. Kajiura (JOSJ, 5, 1949, 19–27), of the area off the Tohoku district by J. Fukuoka and T. Yusa (OM, 4, 1952, 57).

Of the Kuroshio Current, we have several important works. T. Ichiye discussed the hydrography in the Kuroshio area in February and May, giving a theoretical explanation on the meander of this current, the abnormal pattern off Shionomisaki by making use of jet stream theory. He also made use of Rossby's theory of momentum concentration in concluding that the great cold water mass off the Shionomisaki consists of the water upwelled from deeper layers (KH, 2, 1951). He and K. Tanioka also determined the distribution of chemical elements on isentropic surfaces and discussed the effect of horizontal Austausch at different points in the stream axis on TS-curves (PRO, 1950).

The Central Meteorological Observatory, Tokyo, has carried out hydrographic observations regularly in Sagami Bay in 1951 and 1952 and at the weather station (39°N, 153°E) and others (M. Koizumi, KH, 1, 1950; Koizumi and J. Masuzawa, KH, 2, 1952; Koizumi and O. Asaoka, KH, 1, 1950; Koizumi, KH, 2, 1952, T. Nan'niti, OM, 3, 1951, 27–48; M. Hanzawa, OM, 4, 1952; ROWJ, 1, 1953).

Hydrographic observations were also carried out on the Antarctic whaling grounds in the winter months 1950–51 by a fleet of Japanese whalers. About 30 stations were occupied and the results analyzed (M. Hanzawa, K. Kobayashi, K. Yoshida, and R. Marumo, OM, 3, 1951).

Hydrography of the two straits of Isaka-wan, the Akashi-seto and Yuraseto, after heavy rain accompanying typhoon, was discussed by T. Ichiye (PRO, 1949), Ariake Sea and the inland sea in western Kyushu, by Nagasaki Marine Observatory in the summers of 1951 and 1952 to make clear the Kuroshio and the Tsushima Currents in this region. Hydrographic structure in the Tsushima Current area was discussed by T. Tsujita with special reference to its fisheries importance. (Report of the Committee on the Hydrographic Investigations in the Western Part of the Japan Sea, 1952). T. Shinomura and M. Koizumi discussed the hydrography along the section from Tori-Sima (Bonin Group) to off Sanriku District (KH, 2, 1950, 55–74).

The hydrography of the Kumihama Bay, a small inlet facing the Japan Sea, was discussed by K. Hishida (OM, 2, 1950, 67).

The annual variation of sea water temperature in Kii Suido was discussed in detail by T. Ichiye. He showed the possibility of the fore-

casting hydrographic conditions in this area (KH, 2, 1951). M. Nagai discussed the annual variation of sea water temperature and salinity and made several detailed statistical analysis and stressed that their fluctuations due to advocation are very important in forecasting these elements (KJ, 4, 1953).

In 1950 T. Ichiye treated the meandering pattern in the isotherms observed on the surface along the polar front as the horizontal internal waves formed along the boundaries between warm and cold water. (US, 28, 1950).

M. Uda also discussed the characteristic feature of the yearly variation of coastal water temperature and pointed out the advance and lag of the seasons peculiar to each year. His conclusion was that it is most important to carry out the hydrographic observations during the winter months as frequently as possible (US, 30, 1952, 5–7). A survey of the fisheries in relation to hydrographic fluctuation was also discussed by Uda in 1952 (TUFJ, 38, 1952, 363–389).

Classification of the types of the annual variations of water temperature was made by T. Ichiye. He mentioned three types: seas or lakes, bay in which tidal currents are strong, and open sea, with several important discussions (KMOM, 10, 1952).

M. Hanzawa mentions some examples of an abrupt change in hydrographic conditions from his experiences in the observations on board the weather ships. He points out that the advection due to wind effect is responsible for these changes (OM, 4, 1952).

J. Masuzawa gives some examples showing that a typhoon sometimes acts as a motive for the hydrographic changes in the area close to their tracks (KH, 1, 1950, 118–123).

Method of forecasting the hydrographic conditions off Sanriku coast based on the isentropic analysis, was reported by Fukuoka (KH, 1, 1950, 30).

Forecasting sea surface temperature in the southwestern part of the Japan Sea was attempted by K. Hishida (KH, 2, 1951).

The relation between the coastal and offshore water temperature and other hydrographic elements was analyzed by K. Hishida (MMOR, 2, 1951; OM, 2, 1950).

Ocean Currents

In 1950, J. Fukuoka made an analysis of the Oyashio Current flowing south in the area to the NE of Japan. He analyzed the TS-curves from various stations in the Okhotsk Sea and western North Pacific Ocean, and noticed that the Oyashio water and Kuroshio water can be found in some latitudes close together, their boundary always oscillat-

ing northward and southward. From this motion he could determine the velocity of the Oyashio Current (KH, 1, 1950, 10). He also made another attempt to compare the TS-curves of the sea water at various stations and could determine the effect of winds in producing the drift current stations, and could determine the effect of winds in producing drift current (OM, 1951, 97). He also determined the extent of the Oyashio Under Current, which is recognized below the warm water of the Kuroshio (JOSJ, 6, 1951, 202). T. Nan'niti made an attempt to know the year-to-year variation of the Kuroshio and the Oyashio. He says that the Kuroshio was stronger in 1948 and warmer in 1949, and both of these currents were stronger in the period from the spring to the early summer of 1950 (MGP, 2, 1951, 102–111). He also made an attempt to compare the curl of wind stress to the intensity of the Kuroshio. These two quantity must be proportional according to the Modern theories of the drift currents (JOSJ, 8, 1952, 23–29).

A very intensive survey of the flowing patterns of the Kuroshio was reported by M. Uda. He describes the fluctuation of the main axis of the Kuroshio and its margins. The maximum speed and the width of the currents were determined based on the dynamic computations carried out during the period 1934 through 1943. He also explains the abnormal phase of the Kuroshio flowing in a loop to the south of Japan as the effect of the monsoon which was very strong in the winter of 1934–35 in addition to the strengthening of the intermediate water formed as the extension of the Oyashio after it dives below the warm water of the Kuroshio. He also explains the occurrence, development of this abnormal phase of the Kuroshio and its recovery to normal phase, use being made of the past materials (JOSJ, 8, 1951, 181–189). He discussed the variation of the currents in the Japan Sea, Yellow Sea, and East China Sea and showed that the Tsushima Current begins at the 200 m isobath along the margin of the continental shelf of the circulation in the East China Sea (ROWJ, 1, 28–35). Recently Uda described the result of oceanographic observations in the adjacent seas of Hachijo Island in relation to the fisheries (ROWJ, 1, 1953).

Currents in the Japan Sea in the spring and summer, 1949, was described by I. Yamanka, stress being especially laid on the meander of the Tsushima Current which is a branch of the Kuroshio entering this area (JOSJ, 3, 1951, 143). K. Kusunoki described the speed of the currents in the Japan Sea close to the west coast of Hokkaido, northernmost island, and discussed its yearly variation, its periodic cycles and its relation to the fisheries and ice in the Okhotsk Sea (JOSJ, 6, 1951, 133–142).

As to the possible origin of the Oyashio we have the discussion of N. Watanabe, who found that the most part of the Oyashio originates in the water of the Okhotsk Sea and very little amount of the Bering water is considered to take part in the origin of this cold current (JOSJ, 2, 1953).

A very intensive water mass analysis of the Oyashio Current was made by Yukimasa Saito (JIPOCU, 3, 1952, 79–140).

Water Mass Analysis

It is a very important problem in oceanography to separate different water masses and to establish the boundaries between them. Still we have not had yet any reasonable method for them. M. Nagai has succeeded in classifying into 7 blocks the system of water masses in the East China Sea stochastically, numbering the 18 x 9 water types having salinity $29^{o}/_{oo}$, $29\frac{1}{3}{}^{o}/_{oo}$ . . ., $35^{o}/_{oo}$ and temperature 12°, 14°, 16°, . . ., 30°C. (KK, 5, 1951, 54–61).

T. Ichiye used monthly TS-diagram for determining the intensity of monthly mass exchange between the coastal and ocean waters. He showed how the ocean water penetrates into the bay due to the diffusion by eddies. He also discussed the general types of the TS-diagram in the transient region between the ocean and coastal water (KMOM, 10, 1952).

Recently Michio Miyasaki has been considering the use of T-O_2-diagram in addition to TS-diagram. By doing this, he could classify the so-called deep water in the Japan Sea into a number of water masses. He could point out the existence of several important water types in the deep layers of the Japan Sea (HFLB, 7, 1953, 1–65).

The intermediate waters of low salinity in the regions south and northeast of Japan have been discussed by J. Masuzawa in their relation to Kuroshio waters. He pointed out the intense turbulence both in horizontal and vertical directions and determined the horizontal diffusivity at 106–108 c.g.s. on the isentropic surface (t–26.6–26.8), (OM, 2, 1950; KH, 2, 1951, 5–13, 241–245).

Y. Miyake considers that the boron in sea water behaves as a very good indicator for the water masses and recommends the ratio B/Cl as a useful tool in the water mass analysis (US, 30, 1952, 14–18).

Ykimasa Saito published a very detailed water mass analysis for the northern seas of Japan, stress being laid on the research on the Oyashio. He could explain the significance of TS-diagram in exactly the same way as W. B. Stockman tried in 1947 (JIPOCU, 3, 1952, 79–140).

Diffusion

In 1949 T. Ichiye treated the Brownian movement of a particle of water produced by a stochastic extraneous force in a field of Coriolis forces, and determined the dependence of eddy diffusivity upon the latitude. He compared this theoretical result with the horizontal diffusivity determined from the distribution of conservative concentrations in the ocean currents, and showed how the horizontal eddy diffusivity could be determined from the drift of R.V. "Deutschland" in the Antarctic Ocean (OM, 1, 1949).

In 1950 Ichiye considered a statistical theory of turbulent diffusion, discussing the diffusion from an origin by a process similar to Brownian motion, and could explain the so-called scale effect postulated by Lewis F. Richardson (KMOM, 8, 1950). He also made some remarks on Richardson's neighbor diffusion equation (OM, 2, 1950). He applied this theory to the diffusion of water masses in the oceans and gave a qualitative explanation on the variation of the horizontal Austausch coefficient in the ocean currents by developing the spectral theory of turbulence in case where irregular extraneous forces are in action (OM, 3, 1951). Yasukazu Saito solved the problem of diffusion of salinity in a horizontal current field, both horizontal and vertical mixing being taken into account (TUFJ, 38, 1952, 182–191).

T. Nan'niti determined the horizontal and vertical eddy diffusivity using Montgomery's method from the actual distribution of salinity. He obtained horizontal and vertical coefficients to be 10^7 and 10^1 respectively (OM, 3, 1951). From the salinity distribution on the core sheet of the Subarctic Intermediate water near Japan, J. Masuzawa obtained horizontal eddy diffusivity to be 10^6–10^8 c.g.s. (KH, 2, 1951–52). E. Inoue concluded this quantity has a value 10^{10} c.g.s., a value much larger than previously known (KS, 28, 1950, 420–424).

In 1950 Ichiye treated the annual variation of the heat contents at several stations in Osaka Bay as a horizontal diffusion by tidal currents (KMOM, 8, 1950).

In 1952 Ichiye discussed the relation between the O_2 minimum layer and the motionless layer in case where both horizontal and vertical diffusions occur, and showed theoretically how the depth of O_2 minimum layer varies as the distance from the source increases when there is biological dissipation. He determined the schematic distribution of oxygen in the sea when the processes of dissipation, supply and diffusion are going on simultaneously (US, 29, 1952).

On September 17, 1952, a new submarine volcano was observed erupting from the Pacific floor south of Japan. This submarine eruption ejected a great deal of pumice stones afloat on the sea surface,

expanding by diffusion in all directions. From the distribution of pumice stones, M. Hanzawa derived an approximate value of eddy diffusivity to be 4.8×10^6–4.3×10^7 c.g.s. (OM, 4, 1953).

Theories of Wind-Driven Ocean Circulation

According to the recent theories of the oceanic circulation, the main source of energy supply to the major current of the ocean is the semi-permanent wind system over the oceans. During the period 1949–53, very active research has been done on this subject.

T. Ichiye has long engaged in the dynamical research on ocean-currents since 1949 (OM, 1, 1949). In 1950 he discussed the wind-driven currents produced by circular wind system. In this computation he retained the inertia terms and applied the result to the motion of water produced by a typhoon. He showed that an upwelling must occur in deeper levels (OM, 2, 1950). He also discussed the wind-driven ocean circulation in an ocean taking into account the effect of horizontal mixing. His computation is nearly similar to that of Munk (OM, 2, 1950). He also discussed the equation of ocean current involving the inertia terms and solved it for a zonal flow in an asymptotic expansion. By this theory he could show the occurrence of a counter current on the right side of the current looking downstream (KMOM, 8, 1950).

The same year, Masamori Miyazaki computed the coefficients of horizontal and vertical mixing on both sides of a current of uniform velocity by Gebelain's method and obtained the distribution of velocity across the current. He thus concluded that the occurrence of a counter current can be determined by vertical distribution of current velocity (OM, 2, 1950, 53–58). The same year, Miyazaki published a theory of wind-produced zonal current in an ocean completely covering the earth, taking into account the effect of both horizontal and vertical mixing. He could prove that the deviation of current system from wind system decreases, and the subsidence of current with depth increases by the presence of horizontal mixing (KMOM, 8, 1950, 41–43). He gave an expression for the coefficient of lateral mixing for a stationary state and the decaying stage without supply of energy from outside (OM, 2, 1950, 113–116).

In 1951 Ichiye published two papers on the variation of oceanic circulation. In order to explain the double periodicity found by C. O'D Iselin for the Gulf Strea, he discussed successfully the variation of oceanic circulation accompanying the periodic variation of zonal wind system (OM, 3, 1951). He also computed annual variation of the mass and heat transports in five sections across the Kuroshio and described the mechanism of these changes to the density currents due to the phase

lags between the temperature cycles of coastal and offshore waters (OM, 3, 1951).

In 1951 Hidaka published the result of a computation of the general circulation of the Pacific Ocean. This is a modification of Munk's theory, the only differences being the use of spherical coordinates instead of Munk's rectangular, and the assumption of two types of wind system—zonal and anticyclonic. He obtained practically the same result as Munk's, except a better agreement than Munk's of total mass transport with the actual value 65 million tons per second obtained by Sverdrup from Japanese observations. It must, however, be borne in mind that the exact value of total mass transport is very hard to determine, the recent observations by Japanese giving about 20–40 million tons per second (J. Masuzawa, KH, 2, 1951) according to the seasons of the year. This value is far smaller than that of Sverdrup and agrees with Munk's theoretical result pretty well.

In 1952 Masamori Miyazaki published a new theory of the wind-driven circulation and could explain the counter-current observed between the Gulf Stream and the American continent by assuming a zone of smaller value of the coefficient of lateral eddy viscosity close to the coast. This counter-current has been observed from a long time ago and many authors have failed to explain except Rossby, who could solve it by taking into account the effect of inertia terms (OM, 4, 1952).

Yasukazu Saito made a very elaborate mathematical analysis on the theory of ocean currents driven by winds in an isotropic ocean taking into account the mixing in all directions. He used the velocity itself for solving the problems (KS, 28, 1950, 25–61; TUFJ, 38, 1951, 87–179).

Recently Hidaka solved a three-dimensional theory of ocean currents, thus making it possible to discuss the vertical structure of wind-driven current. The most outstanding conclusion is that the motion of water is much more intense than is expected in layers far below than the depth of frictional influence defined by Ekman (in press).

As to the fluctuation of oceanic circulation caused by the wind fluctuation, Ichiye made an attempt to determine the curl of the wind stress in each 5° square over the Pacific from actual observations. Further he could determine the annual variation of the horizontal mixing coefficient on the basis of the spectral theory of turbulence, and discussed the variation of circulation equalitatively (OM, 4, 1952).

In 1952 K. Kajiura used the idea of Sverdrup and Reid in computing the current velocities in the upper layers of the eastern portion of the equatorial Pacific on the assumption that the initial forces and the lateral friction are negligible. He divided the motion into two parts, that is, the pure drift currents and the relative currents, and showed

that the result agrees satisfactorily with the observations near the equator. In this region the relative current is much stronger than the pure drift current, while the meridional components of currents are negligibly small compared with the EW-components (JOSJ, 8, 1952, 15–22).

The dependence upon the bottom friction of sea surface slope induced by wind is discussed theoretically by Ichiye. He determined the vertical structure of drift currents and compared it with actual observations. He also obtained the drift current when Rossby's expression for the vertical mixing coefficient is used (KMOM, 10, 1952).

Recently K. Yoshida treated successfully the problem of circulation in the upper mixed layer in the equatorial region of the North Pacific Ocean by solving the steady state equations involving terms of Coriolis forces, pressure gradient, and horizontal as well as vertical mixing (Hoshida, Han-lee Mao, and Paul L. Horro, in press).

The most part of the theories described above is obtained on the assumption that the inertia terms in the dynamical equations are negligibly small compared with the remaining terms. The significance of these terms in dynamical oceanography was discussed by Hidaka and M. Miyoshi (GN, 2, 1949). A similar discussion was made by Ichiye, who concluded that these terms cannot be neglected when the curl of the wind stress is large, and estimated their magnitude (OM, 2, 1950).

The simplification of the theory of the wind-driven ocean current will be approached by assuming a zonal ocean and a planetary wind system so that both winds and currents are independent of longitude. Theories were worked out by Hidaka and his collaborators K. Takano and M. Tsuchiya (GN, 3, 1950; GM, 23, 1952, 487–495; JMR, in press).

A very important question in dynamical oceanography is how and in what proportions the energy of wind is imparted to raising waves and producing currents. This problem was discussed by K. Yoshida (JOSJ, 7, 1951) and Ichiye (OM, 4, 1952).

In 1952 K. Kajiura discussed on the currents and the accumulation of water produced by winds in the water consisting of two layers of different densities. He assumed that the eddy viscosity is negligible along the boundary of two layers and showed that the shape of the boundary surface agrees very closely with observations (JOSJ, 8, 1952, 67–71).

Upwelling and Coastal Currents

Recently K. Hidaka propounded a hydrodynamical theory of upwelling. He assumed an infinitely long straight coast and constant latitude, and discussed the upwelling to be produced as the effect of wind blowing in a belt of a certain width from the coast. He took the

Coriolis forces and horizontal and vertical mixing into account. For the values of mixing coefficients generally accepted, the velocity of upwelling was computed at about 80 meters per month for the wind speed 5–6 m/s and the latitude 30°N, thus coinciding closely with observations and former estimates. He also showed that the most intense upwelling will occur when the wind makes an angle 21–5° with the coast line in an offshore direction. The horizontal motion involved in this circulation can be considered to form a part of the coastal or longshore currents much debated recently (Technical Report, Department of Oceanography, Texas A. & M., 1953).

In 1950 T. Ichiye, discussing the wind-driven currents produced by a circular wind system, could show that the upwelling must take place in deeper layers even in an open ocean (OM, 2, 1950).

Yukimasa Saito published a simple method of computing the vertical velocity of water from the displacement of isophonals. This method will be very useful when the distribution of density is given at a certain interval of time. He applied his method to the upwelling off Southern California and obtained the velocity of upwelling 2.55 m/day or about 80 m/month (JIPOCU, 2, B, 1951, 1–4).

Tides and Tidal Currents

N. Okamoto, Masamori Miyazaki, and H. Yoshizawa succeeded in obtaining four principal components of tidal currents from fortnightly observations in June, 1951, by Ono's recording current meter working on the No. 2 Buoy in the Osaka Harbor (KH, 2, 1952, 29–34).

Masamori Miyazaki obtained the tidal harmonic constants for Kobe and Sumoto by the Tidal Institute Method of A. T. Doodson (KH, 2, 1951, 21–24).

Z. Yasui and S. Ishiguro published an intensive survey and description of the tidal currents in Hirado Channel near Nagasaki. They made a model experiment at the same time and could explain observed results very satisfactorily (NMOR, 3, 190). H. Akamatsu made a very intensive survey of the tidal and nontidal currents around the Goto Islands to the northwest of Kyushu (KK, 4, 1950, 65–72).

K. Hishida made a survey of currents, tidal or nontidal, close to the coasts of the Japan Sea and showed that a marked vertical variation is noticed in them, which may be explained as due to winds and bottom topography (MCAKU, 62, 1952).

Ichiye reports the observations of tidal currents and waves in Osaka Bay, the Harima Nada, Kii Suido (PRO, 1949; US, 28, 1950; KH, 2, 1951; Report on the Investigations of the Beach Erosion in the southeastern part of Osaka Bay, 1).

Adventional variation of temperature and salinity due to tidal currents was discussed by T. Ichiye (OM, 4, 1952). He also treated the modification of wave form when a long wave propagates through a channel of varying sections. He applied his theory to the Akashi Seto, a channel connecting Osaka Bay to another basin situated to the west, and computed the permeability of the waves when two eave trains meet in this channel (KMOM, 9, 1951).

A new development in the discussion of the tidal currents in the Straits of Shimonoseki separating Honshu and Kyushu, two major islands of Japan, was made by Mashito, Nakano. He also pointed out a comment about its prediction (GJ, 58, 1949, 213–216).

Seiches and Secondary Undulations of Tides

On the occasion of cyclonic storms attacking our islands we frequently notice oscillations of period 1–3 minutes accompanying the tidal oscillations on mareograms. This phenomenon, now called "surf beats," has been long known in Japan. M. Nakano reports a remarkable series of such undulations which accompanied the storm of 1–5 April 1936, and observed on the mareograms of tidal stations along the Japanese coasts. Nakano gives a very intensive examination of this phenomenon (OM, 1, 1949, 13–32).

T. Ichiye treated theoretically the oscillations which will be caused by a sudden impulse of wind exerted on the sea surface and obtained the relation between the shape of the bay, time variation of the stress and the amplitude. He pointed out that an impulsive stress is more effective on producing seiches (JOSJ, 6, 1950).

Sea Level

In 1951 S. Yamaguti showed that the monthly mean sea-level corrected for astronomical, meteorological, and oceanographical effects, can be fairly used for discussion of the vertical displacement of the earth's crust and sometimes may be used in place of precise levelling (GSB, 2, 1950).

Waves

Studies of waves have been made partly in connection with some practical applications. Forecasting of waves and swells has been needed for the safety of ships, for protection of coasts and harbors, and in connection with various problems of coastal engineering. These forecasting and practical studies have mainly been carried out by the staff of the Hydrographic Office, Central Meteorological Observatory, and a number of branch organizations (M. Nakano, S. Unoki, and K. Yuge, OM, 5, 1953; H. Arakawa and K. Suda, MWR, 81, 1953; M. Uda, GM,

23, 1952; Yoshida, Kajiura and Hidaka, ROWJ, 1, 1953; K. Sato, HB, 16, 1950; HB, 25, 1951; Miyazaki, KS, 28, 1950; I. Kimura, CKH, 1, 1949; H. Yamada, FE, 5, 1949; T. Ichiye, KH, 2, 1951; H. Hikada *et al.*, KH, 1, 1949). To locate and track the storm or typhoon over the ocean, studies of microseisms in relation to the ocean waves have been continued in the Earthquake Research Institute and in the Central Meteorological Observatory. (F. Kishinoue, ERIB, 29, 1951, 277–282.) Studies of beach erosion problems have been made with particular activities, under the cooperation of various research groups. Experimental studies of surf in a model tank which were made by T. Hamada have made an important contribution to this field. (Transportation Technical Research Institute, Report No. 2, 1951, 1–165.)

Theoretical studies of wind waves have been made by K. Yoshida. He pointed out the importance of the process concerning the mutual exchange of momentum between ocean waves and ocean currents (K. Yoshida, JOSJ, 7, 1951, 99–104). He suggested that energy transmitted from wind to water goes partly into waves and partly into currents, and furthermore, energy is transferred from shorter waves to longer waves and also from waves to currents, mainly due to semi-irregular breaking of waves. Based on a physical consideration, he derived an equation to find an energy portion required to increase wave height and wave velocity respectively, and therefrom an equation of wave growth which slightly differs from Sverdrup-Munk's (K. Yoshida, GN, 4, 1951). Energy distribution in wave spectra, which results from his theory of energy transfer from shorter waves to longer waves, was compared with actual wave data (K. Yoshida, JOSJ, 7, 1951, 49–54). Based on nonlinear equations of waves with continuous spectrum, he suggested that the frequent occurrence of waves of several minutes' period, surf beats, may be ascribed to the general structure of the ocean wave spectrum (K. Yoshida, GN, 3, 1950). Periods of surf beats are estimated approximately from an original spectrum; $T = \frac{2L^2}{\Delta T}$ where T denotes a period of energy maximum, and ΔT is the range of periods of wave components with a significant amount of energy. M. Nakano published a paper in 1949, Yoshida attempted to find a modification of swell in shallow water, where a bottom slope is not gentle enough to allow an ordinary refraction diagram approximation to be valid (K. Yoshida, GN, 3, 1950). However, available wave records have not been sufficient to prove and support these theories so far.

An electrical recorder of waves was devised by S. Ishiguro, a very able hydrographic mechanician. He constructed several types of wave recorders and an apparatus for the stroboscopic analysis for preparing the wave spectrum (S. Ishiguro, OM, 1, 1949; KK, 3, 1949; KK, 4,

1950; K. Sato, HB, 15, 1949). Wave recorders of pressure type have been installed at several parts of our coasts, and especially continuous records at Yogashima Island have been analyzed by the staff of the Oceanographic Section of the Central Meteorological Observatory (M. Nakano, S. Unoki and Y. Kuge, OM, 5, 1953, in press). The accumulation of such data as well as activities of the staff may afford a promise of progress in forecasting. One of the most successful and interesting results from the wave recorders installed by this staff is that a recorder at Hachijo Island recorded long sea waves (tsunamis) produced by an eruption of a submarine volcano in September of 1952, and that S. Unoki and M. Nakano could explain the observed change of period and district beat phenomena by solving the wave problem of Cauchy-Poisson type (S. Unoki and M. Nakano, OM, 4, 1952; OM, 5, 1953). This record at the station 130 km. distant from the volcano showed that the period decreases gradually with the lapse of time, from 95 sec. to 30 sec., and also showed distinct beat pattern. A stereophotogrammetric study of the surface was atempted by K. Sato, who was lost on board the wrecked vessel at the eruption of the Myojin volcano.

In 1951 and 1952, Masamori Miyazaki published papers on mathematical studies of surf and breakers in water of constant slope (Masamori Miyazaki, OM, 3, 1951; OM, 4, 1952). He also discussed the wind stress over the wavy sea surface mathematically (OM, 3, 1951). A problem of "tidal race" was taken up by Miyazaki in 1949 and by T. Ichiye in 1951 (Ichiye, OM, 1, 1949; Miyazaki, OM, 1, 1949). K. Hidaka published two papers of surface waves in 1951. He proposed a very simple explanation as to why the group velocity is equal to the velocity with which we can follow the waves without change of wavelength (K. Hidaka, JOSJ, 7, 1951). Hidaka and A. Nakano calculated the surface profile of high waves from Stokes' equation by means of numerical calculations instead of successive approximation procedures (Hidaka and A. Nakano, JOSJ, 7, 1951).

Storm Tides

Ariake Sea, which is a shallow water in the island studded part in western Kyushu, has a big productivity. This area is much frequented by typhoons. A computation was made by K. Terada as to how high the storm tides accompanying the passage of typhoons would be. A theory for such a phenomenon had been established by several persons immediately after the "Muroto" Typhoon which caused serious damage in the heart of Japan by a heavy storm tide in 1934. Masamori Miyazaki is one of those who recently solved the problem of storm tides caused by a travelling storm in an infinite and semi-infinite seas (OM, 4, 1952, 1–12).

The storm tides caused by a heavy typhoon which attacked Japan in September, 1950, were also examined by Masamori Miyazaki in 1951. The storm tide-height amounted to about 125 cm. along the Kyushu coast facing the Inland Sea.

He also analyzed the data obtained during the passage of the typhoon "Muroto" (1934) and the typhoon "Jane" (1950), which went across Osaka Bay, and made some additional explanation of the seiches with periods 310 minutes and 70 minutes which were observed during the passage (KH, 2, 1951). The storm tide caused by the typhoon "Jane" was also discussed by K. Hishida and T. Wakabahashi and was reported to have amounted to a height of 60–70 cm. (KH, 1, 1950, 185).

A series of dynamical studies was made by S. Unoki during the period 1950–51 on the effect of atmospheric pressure change on the variation of sea level. He found that the sea level always responds to the variation of the atmospheric pressure after a lag of time. This lag is found to increase with the period of the atmospheric pressure variation, velocity of travelling surface pressure disturbance and the latitude, and decreases with the depth of the sea. These observed facts were shown to agree with the theory pretty well (OM, 2, 1950, 1–15). He also made an attempt to improve the Colding formula for estimating the elevation of the sea level caused by stationary winds. He studied the effect of the fetch, variation of depth and the gradient of wind velocity on the variation of sea level (OM, 3, 1951, 1–16). He further pointed out that the lag between the wind and the sea level variations is usually small when only the wind direction varies, but the phase-difference is large when the wind force varies, being closely related with the latitude, the angle between the wind and coast line, and the rate of variation of wind velocity. But the most important conclusion he obtained is that the elevation of sea surface is considerably larger when the wind direction rotates counter-clockwise than when it does clockwise, even when the absolute value of wind velocity and the rate of variation of wind direction remains the same. This means that larger elevation of the sea surface occurs when a cyclonic storm passes northward across the west side of a bay, than when it passes through the eastern portion (OM, 3, 1951, 53–63).

In 1952, K. Kajiura made a study of the currents and the accumulation of water caused by winds in a lake whose water consists of two layers of different densities. The computed profile of the boundary layer agrees with the observation satisfactorily (JOSJ, 8, 1952, 67–71).

A series of remarkable papers was published by H. Yamada on the effect of a travelling disturbance on the motion of water in an enclosed or a semi-open sea. After a tedious computation, he could show the

detail of water movement accompanying the passage of storm across these basins (FE, 6, 1950, 22–33).

Tsunamis

The coastal areas of Japan have frequently been attacked by the storm waves (surges, or Takashio) caused by typhoon and also by tsunamis caused by submarine earthquakes. To protect the coastal areas from damages due to such high waters, a number of studies has been made on these problems.

A series of theoretical research was published in the years preceding 1950 by R. Takahashi. In 1951, he published a very intensive work on the amount of energy of tsunami waves arriving per unit length of segment along the Pacific coasts of the Japanese islands per century. This research is very useful to anticipate the possible damages by tsunami attacking our islands in future, providing the seismic activities remain unaltered for the time being (ERIB, 29, 1951, 76–96).

T. Ichiye has published another series of papers on tsunami. In 1949, he made a model experiment of the tsunami waves entering Osaka Bay from the Pacific Ocean and studied the patterns and characteristics of the oscillations peculiar to several portions of this bay around which are located many important industrial and commercial cities in the heart of Japan. He also attempted to take the effect of viscosity into consideration (KS, 26, 1949).

Afterward he propounded a theory of tsunami and discussed the reflection and penetration of tsunami waves as they pass into the shelf taking into account the interrelation between the length and period of tsunami waves and the depth and bottom slope of the shelf, and obtained a correction to Green's law of change in amplitude. He also succeeded in computing the reflectivity and permeability of tsunami which attacked Osaka Bay just mentioned from several directions of the Pacific. He also took into account the effect of viscosity on the shelf (KS, 27, 1949; OM, 2, 1950). He also established a theory of tsunami caused by a travelling disturbance on the bottom. This theory of tsunami produced by a moving source is very helpful in treating the observed waves of tsunami. He first computed the tsunami waves when the submarine dislocation moves in a direction and showed that there occurs in a train of waves if the velocity of source is smaller than that of long waves, and a solitary wave is produced when the source moves faster than the long wave (KMOM, 8, 1950). Next, he treated the case where a circular elevation or depression is moving on the bottom. The patterns of oscillations remain the same except that the wave height decreases as the reciprocal of the square of the distance (KMOM, 9, 1951).

It has been a common sense that the tsunami wave becomes highest at the head of a bay. But, according to the observed data of the Sanriku Tsunami, March 4, 1952, this was proved not to be necessarily the case. To explain this fact, Ichiye assumed a frictional resistance on the bottom of the bay head and had the conclusion that the amplitude becomes a maximum at the middle portion of the bay (KMOM, 10, 1952).

Although these papers are very excellent, it might be more advisable now to have a tsunami recorder and to analyze the records more in detail. D. Shimozuru and T. Akima found tsunami waves of long period, about 80 minutes, superposed on shorter period waves of tsunamis in the tidal record of December 21, 1946, by means of mechanical law-pass filter of torsion pendulum type. The investigation of the phase of the long period waves appears to indicate that they are due to the reflection from Guam Island (ERIB, 30, 1952, 223–230).

The accounts on the Sanriku Tsunami, March 4, 1952, have been published by several authorities including the Earthquake Research Institute and Geophysical Institute, Tokyo University, and the Central Meteorological Observatory, and others. In the Geophysical Institute, Tokyo University, an expedition was issued for the investigation and the report on tsunami waves and its patterns was published by K. Yoshida, K. Kajiura, and H. Miyoshi (JOSJ, 8, 1953). An importance of the reflection of tsunami waves by continental slope was pointed out in this report. In the case of this tsunami, a warning system was successful. Various problems having been discussed concerning the propagation of tsunami waves (T. Ichiye, US, 26, 1949; T. Ikano, CKH, 2, 1950; S. Homma, KS, 28, 1950; T. Rikitake, ERIB, 29, 1951), interesting is an application of diffraction problem to tsunamis which was made by K. Hidaka and S. Hikozaka concerning a distribution of wave-height on the coasts of Kausi Island in the case of the Hawaiian tsunami of 1946 (JO, 5, 1949). Similar discussion was also made by S. Homma (GM, 21, 1950). Contributions were also made by model experiments of tsunami which S. Ogiwara, and T. Okita attempted (CKH, 2, 1950; SRTH, 2, 1950).

It should also be mentioned that records of the sea shock on August 10, 1949, were obtained by S. Takagi, using a seismograph installed on board an anchored ship (US, 27, 1950). Another important work is a theoretical discussion of flood waves by S. Yayami, the importance of lateral mixing being introduced (Disaster Prevention Res. Ins. Bull., 1, 1951).

Marine Meteorology

In 1950, Arakawa made a statistical survey of the visibility in the Northwestern Pacific Ocean using the data observed by the Japanese

Navy during the period of ten years beginning September, 1923. He found that the visibility is excellent in low latitudes almost all the year round. In high latitudes, poor visibility predominates, especially in the summer months. In the Far East the Summer Monsoon is directed from south to north, so the conditions will be favorable for advection fogs. In the colder half of the year, the obscuring snow in the rear of winter cyclones on the northern sailing routes reduces visibility as a rule (MGP, 1, 1950, 58–66). Based on the materials from the same sources, he and Tsutsumi also discussed the seasonal changes of daily frequency of squalls in the same area. He concluded that the frequency of squalls is drastically large in the Equatorial belt east of Longitude 125°E and south of Latitude 10°N, where the rainfall is heaviest in the Pacific as mentioned by G. Schott in 1938 (MGP, 1, 1951, 296–301).

In 1951, Hokodate Marine Observatory carried out the observations of fogs around his northernmost island very close the polar front and confirmed many of former conclusions on this phenomenon, together with the fact that there are very few of the short period components in the turbulence when the fog is very dense and the lapse rate of temperature is small close to the sea surface (KJ, 4, 1952, 81–120).

A statistical study was made by M. Hanzawa and T. Inous on the influence of the variation of sea surface temperature and pressure on the growth of rice crop (KH, 2, 1952).

Instruments and Methods

In 1950 K. Ono of the Japanese Hydrographic Office, Tokyo, designed an electric shelf recording current meter. This instrument has undergone several improvements and has been used in several areas around the Japanese Islands with success. Another design with a photoelectric cell tube is also published by T. Nan'niti though we have not heard of its widespread use (MGP, 3, and 4, 1953, 286–294).

In 1950 Nan'niti designed a lazy thermometer and tried a theoretical consideration on its time lag.

S. Agari made a design to measure the deep water temperature on deck by the use of an electrically controlled distant deep-sea reversing thermometer. This consisted of a thin carbon thread sealed in a glass tube. The electric resistance is measured by platinum electrodes attached on this carbon thread. He made tests with both protected and non-protected reversing thermometers (KJ, 8, 1953).

Shizuo Ishiguro is a very good designer and constructor of oceanographic instruments. He designed a sea wave height recorder taking advantage of the buoyancy of a cylindrical buoy placed in the water (KK, 4, 1950, 45–53).

He also made an electric recorder for sea wave pressure. The transducer of pressure gauge is of a variable mutual induction type using about a 100 cycle/sec. constant audit frequency. The recording apparatus consists of six parts: a carrier wave oscillator, a modulator combined with the pressure gauge, an amplifier and detector, an automatic calibrating suit, a direct inking oscillograph and an electrical power supply, all kept in four portable cases. This apparatus can measure the wave pressure from 0 up to 50 ton/m^2 with an accuracy of 2 to 3% in pressure and 1/20 sec. in the period of pressure pulsation. Actual observations with this instrument proved successful. He made several improvements (OM, 1, 1949, 135–141; KK, 1, 1948, 2, 1949).

Besides the wave recorder, Ishiguro devised an experimental analysis method for the forced oscillation of water in a lake or sea. The first method is to take movie pictures of the sea surface illuminated by a nearly horizontal beam. He also replaced the oscillating water in a basin by a combination system of electric impedance, the solution being shown in a cathode oscillograph (KK, 4, 1950, 59–84).

Ishiguro applied the techniques of photogrammetry in order to measure the progressive phenomena on the sea surface such as tide waves, and wind waves and swell (KK, 4, 1950, 35–39).

He also devised a drawing instrument or graphic computer to analyze an irregular wave-form, or to combine different wave patterns, an optical direction recorder for tidal currents and an electric-contact-type speed recorder for submarine currents (KK, 4, 1950, 18–20, 21–23). Unfortunately these instruments have not yet been constructed because of his illness.

A nomograph diagram for the temperature correction of a non-protected reversing thermometer is given by Y. Takenouti and T. Kato (KH, 1, 1950, 53–56).

The technique of determining the ocean currents by measuring angle and direction of maximum inclination of the sounding wire was studied by K. Fukutomi (CKH, 1, 1951). The relation between the wind and the surface drift was discussed by K. Hishida (JOSJ, 6, 1950).

In 1952 T. Abe made a different model of bathythermograph (KH, 2, 1952, 289–296).

An undersea observation chamber "Kuroshio" was constructed in Japan and operated by N. Inoue, T. Sasaki and R. Oaki. This instrument, very similar to the bathysphere used by W. Beebe and Otis Burton in the United States of America was constructed in 1951. This project is financed by the Yomiuri Shinbun, one of the biggest newspaper companies in Japan, the Japanese Government, and others. This was used in the summers of 1951 and 1952 with success. (Journ. Scient.

Res. Ins. 46, 1952; ROWJ, 1, 1953, 52-62; N. Suzuki and K. Kato, Bull. Fac. Fish. Hokkaido Univ. 4, in press.)

The production of deep-sea reversing thermometers, both protected and non-protected, has greatly increased recently. Nearly two hundred of them have been exported to the United States and many other countries of the world. S. Watanabe and S. Yoshino are two of the outstanding makers.

Submarine Geology

In 1950 K. Hishida made an investigation on the sand drift in Takahania Harbor in the Japan Sea coast of Japan (KH, 1, 1950, 193).

T. Ichiye published a series of papers on the beach erosion along the southeastern coast of Osaka Bay. He propounded a theory of beach erosion and suggested that the intense beach erosion is accompanied by converging currents (US, 26, 1951; Reports on the Investigations of Beach Erosion in the Southeastern Part of the Osaka Wan, 1951, 1952).

Hiroshi Niino is carrying on a very extensive geological survey in several areas in the adjacent seas of Japan by boats belonging to the Tokyo Fisheries University. His surveys are regarded to be very important from the standpoint of locating the fields of coal, oil and natural gas.

ABBREVIATIONS

The following abbreviations are used in the text for expressing names of the publications:

CKH ..... Chikyubuturigaki Kenkyu Hokoku, Hokkaido University, Sapporo.
ERIB ..... Bulletin of the Earthquake Research Institute, Tokyo University, Tokyo.
FE ..... Reports of the Research Institute for Fluid Engineering, Kyushu University, Fukuoka.
GJ ..... Journal of Geography, Tokyo.
GM ..... Geophysical Magazine, Central Meteorological Observatory, Tokyo.
GN ..... Geophysical Notes, Geophysical Institute, Tokyo University.
GSB ..... Bulletin of the Geographic Survey Institute, Tokyo.
HB ..... Hydrographic Bulletin (Suiro Yoho), Japanese Hydrographic Office, Tokyo.
HFLB ..... Bulletin of Hokkaido Regional Fisheries Research Laboratory, Yoichi, Hokkaido.
JCSB ..... Bulletin of Chemical Society of Japan, Tokyo.
JIPOCU ... Journal of the Institute of Polytechnics, Osaka City University, Osaka.
JMR ..... Journal of Marine Research.
JO ..... Journal of Oceanography.

JOSJ ..... Journal of the Oceanographical Society of Japan, Tokyo.
JSSI ..... Journal of the Japanese Society of Snow and Ice, Tokyo.
KJ ..... Chuo Kishodai Kenkyo Jiho (Journal of Meteorological Research), Central Meteorological Observatory, Tokyo.
KH ..... Kaiyo Hokoku (The Oceanographical Report of Central Meteorological Observatory, Tokyo).
KK ..... Kaiyo to Kisho (Oceanography and Meteorology), Nagasaki Marine Observatory, Nagasaki.
KMOM .... Memoirs of the Kobe Marine Observatory, Kobe.
KS ..... Kisho Shushi (Journal of the Meteorological Society of Japan), Tokyo.
MCAKU ... Memoirs of the College of Agriculture, Kyoto University, Kyoto.
MGP ..... Papers in Meteorology and Geophysics, Institute of Meteorology, Tokyo.
MMOR ..... Maizuru Marine Observatory Report.
MWR ..... Monthly Weather Review, Washington, D.C.
NMOR ..... Nagasaki Marine Observatory Report.
OM ..... Oceanographical Magazine, Central Meteorological Observatory, Tokyo.
PRO ..... Papers and Report in Oceanography, Kobe Marine Observatory, Kobe.
ROWJ ..... Records of Oceanographic Works in Japan, Japan Science Council, Tokyo.
TK ..... Teion Kagaku (Low Temperature Science), a publication in Japanese, edited by the Low Temperature Institute, Hokkaido University, Sapporo.
TUFJ ..... Journal of the Tokyo Fisheries University, Tokyo.
US ..... Umi to Sora (Sea and Sky), published by the Marine Meteorological Society, Kobe Marine Observatory, Kobe.
SRTH ..... Science Reports of the Tohoku University.

OCEANOGRAPHY IN MALAYA

The Analysis of the Marine Eco-System as a Basis for Prediction of Fish Availability in Malayan Seas.

By D. W. Le Mare

Sea fishing is essentially the exploitation of a natural resource by the capture of a portion of wild stocks from an uncontrolled environment. The success of the operations depends on an intimate knowledge of the nature and habits of these stocks. Normally, experienced fishermen have a fairly good idea as to where and when to ex-

pect different species of fish. Very often, however, much time is wasted in searching for the fish and from time to time there have been reports from various parts of the world of unusually small catches or even of complete failure of certain fisheries. On the other hand there are occasions when catches are normally poor. The fishermen are unable to explain these phenomena so that, from the point of view of financiers, the fishing industry is generally considered to be inherently hazardous and does not attract finance so readily as other enterprises. There are, of course, other factors but this element of uncertainty in fish production is the largest factor which retards the expansion of the fishing industry on sound economic lines. It is clear, therefore, that for the fishing industry to operate on an economic basis the fishermen must be supplied with, inter alia, information as to where and when each species or group of species of fish is available for fishing operations. This is a task which should be given the highest priority in fishery investigations as until it is known where, when and at what depth each species of fish is available it is not possible to decide where to study the nature of the bottom, the sea currents and the meteorological conditions in which the fishing operations have to be carried out effectively without a knowledge of all these factors. The need for reliable prediction systems have been felt in different parts of the world and many have been elaborated. The use of indicator organisms for the Herring fishery in the North Sea is an example. It is of special importance in the underdeveloped areas to know when and where to go, so that the production of food for the world's growing population may be increased with a minimal waste of effort.

In Malaya, however, the catches of many of the tears in use at the present moment consist of mixed fish and it has been found that while these fish show a certain amount of food preference, they are mostly plankton feeders and readily feed on other organisms if the food preferred are not available. Details of the results of the investigations on the food and feeding habits of the fishes in Singapore Straits are given in a paper by Tham Ah Kow (1950). There is evidence also that there is a close correlation between wind and catches of certain species of fish such as Stolephorus spp. This is not surprising in view of the fact that the currents in Malayan seas are largely monsoon currents. From the experience gained in the study of the fisheries of Malaya over the years, it would appear also that rainfall and salinity variations as well as variations in plankton play some part in the variation in availability of fish.

In view of these considerations, it was decided that a concurrent study of the physical, chemical and biological factors as related to the

availability of fish should be made by the Research section of the Malayan Fisheries Department. For this purpose it was decided to concentrate all observations in Singapore Straits since, besides other considerations, one of the main gears used in this area is the fixed fish trap known as the Kelong. The important features of this method of fishing are: (1) in Singapore Straits its fishing intensity is practically constant; (2) the fish in Singapore Straits are brought on to the long leads of these traps by the tides and all fish lured into these traps are caught by means of fine meshed lift nets; and (3) reliable records of the catches of these stakes are easily obtainable. A detailed description of this gear is given by Le Mare and Tham (1947). Observations on the following factors were made at regular fortnightly intervals during two full years: (1) sea water temperature, (2) salinity, (3) phosphate content, (4) phytoplankton, and (5) copepod numbers. Full details of the methods used in the measurement of these factors are given in a paper by Tham Ah Kow (1953). It should be stated, however, that in the case of phytoplankton the estimation of pigment content by Harvey's method as well as total counts were carried out. Data on wind-force and rainfall for the period of the investigations were supplied by the Malayan Meteorological Service.

In an attempt to study the effect of each of these factors on the availability of fish the data so obtained were subjected to correlation analysis by means of partial correlation. As the data are based on fortnightly samples, they constitute time series and it is possible that in each of these time series the value of the variable at one period of time may influence its value in a succeeding period. In such cases the use of partial correlation as an analytical tool would not be valid. However, according to Bartlett (1953) there should be no objection to the use of partial correlation as a preliminary measure. If the partial correlation coefficients are quite insignificant, there does not seem much point in considering them any further. If the correlation coefficients appear significant, then the terms of each of the series should be tested for independence and if found to be independent the partial correlation coefficients may be accepted as valid. This procedure has been adopted. Where the terms of both series correlated are not independent then the method of Fisher (1948) for series correlation is applied to remove the effect of time. The results obtained by this correlation analysis are shown in Figure I.

The main elements of the fish population in Singapore Straits are Stolephorus spp. (anchovy), Clupea spp. (sprat), Chirocentrus spp. (dorab) and Scomberomorus spp. (Spanish mackerel). They are inter-

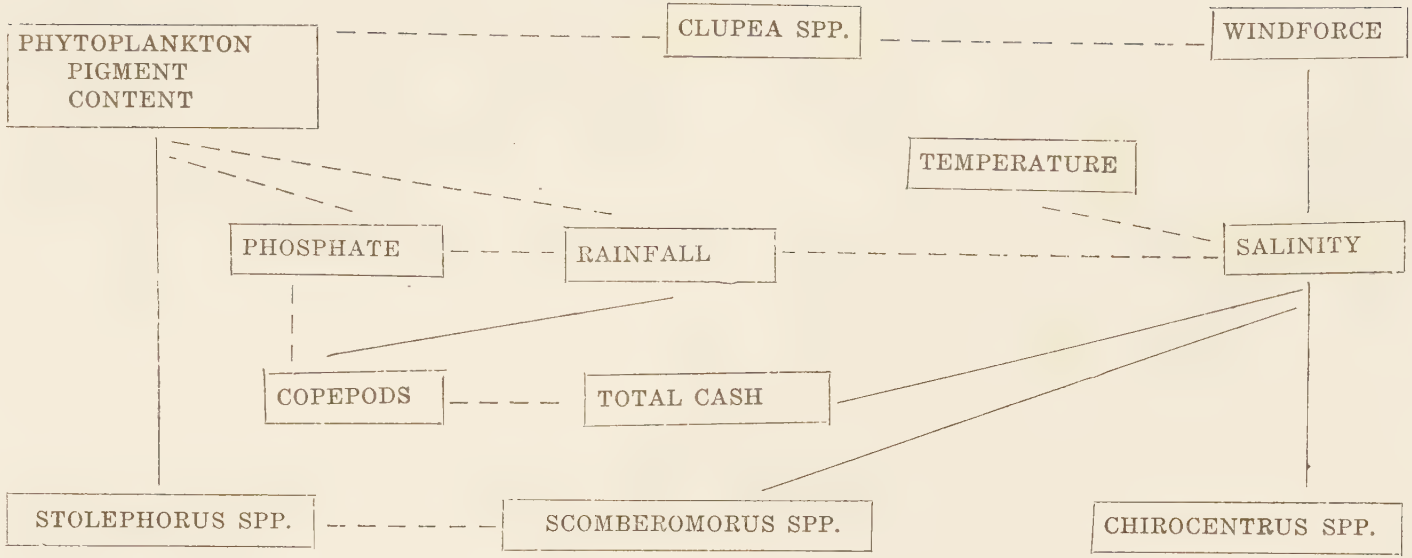
PHYTOPLANKTON PIGMENT CONTENT
CLUPEA SPP.
WINDFORCE
TEMPERATURE
PHOSPHATE
RAINFALL
SALINITY
COPEPODS
TOTAL CASH
STOLEPHORUS SPP.
SCOMBEROMORUS SPP.
CHIROCENTRUS SPP.
STATISTICALLY SIGNIFICANT.
PROBABLY STATISTICALLY SIGNIFICANT.

FIGURE I

related in that both Scomberomorus spp. and Chirocentrus spp. feed voraciously on Clupea spp. and Stolephorus spp. These latter groups, in turn, feed on zooplankton (especially copepods) and phytoplankton. The physical and chemical elements of the environment play an important part in determining the availability of plankton as well as the various elements of the fish populations. It is clear, therefore, that the various elements of the marine eco-system in Singapore Straits are very closely integrated.

In an attempt to study further the close relationship between the fish population on the one hand and the environmental conditions, viz: rainfall, windforce, temperature, salinity, phosphate, phytoplankton and copepods, on the other, the method of multiple regression is used. The multiple regression equation obtained may be expressed as follows:—

$$X_{14} = -49{,}903 - 395.61100\ X_2 - 1.77415\ X_3 - 1{,}105.75115\ X_4 - 1{,}269.82920\ X_5 - 0.47599\ X_7 - 72.13537\ X_8$$

where X_{14} = the monthly total catch of three kelongs in pounds,
X_2 = total rainfall in inches for that month,
X_3 = total wind speed in metres per second for that month,
X_4 = average temperature of the sea water in °C for that month,
X_5 = average salinity in $^0/_{00}$ for that month,
X_7 = average number of phytoplankton cells and/or chains of cells per cubic metre for that month,
X_8 = average number of copepods per cubic metre for that month.

On testing the significance of the multiple correlation by working out the value of "z" it is found to be 0.87977 whilst the 0.1% point is 0.8657. The multiple correlation is therefore clearly significant. The adjusted multiple correlation coefficient squared is $R^2 = 0.5566$. The standard error of estimate S is = 2316 lbs. This is 14.44% of the mean monthly total catch for the two years under study.

The total catch for each month for the two years 1948 and 1949 has been calculated and compared with the corresponding actual total monthly catches in Table I. In the above regression equation it is assumed that all the relationships are linear. If it were further refined statistically by taking into account the curvilinear nature of some of the relationships a much closer estimate would, in all probability, be obtainable. The results of the multiple regression shows that if predictions of the independent variates could be made with accuracy a prediction system of sufficient accuracy for catches in Singapore Straits is within reach. It would appear also from these results that, in the exploration of new grounds, an intensive study of the marine eco-system should yield a comprehensive picture of the habits and migration of the fish stocks in a comparatively short time.

It is believed that this is the first time that a prediction system for availability of fish has been developed, which shows the present degree of accuracy when tested over a period of 24 months.

TABLE I

Comparison of Actual Total Catch and Calculated Total Catch

Year 1948	Calculated Total Catch	Actual Total Catch	Cal. × 100 / Actual	Difference Act.-Cal. Lbs.
January	6,428	7,029	91.45%	+ 601
February	15,799	17,153	92.11%	+1,354
March	15,421	18,439	83.63%	+3,018
April	17,737	17,520	101.24%	− 217
May	18,793	15,546	120.88%	−3,247
June	17,967	17,618	101.98%	− 349
July	14,809	11,270	131.40%	−3,539
August	15,655	17,364	90.16%	+1,709
September	16,768	16,589	101.08%	− 179
October	20,917	20,536	101.86%	− 381
November	17,483	20,585	84.93%	+3,102
December	12,504	13,125	95.27%	+ 621
Year 1949				
January	12,224	11,249	108.66%	− 975
February	16,323	12,381	131.83%	−3,942
March	17,983	19,321	93.07%	+1,338
April	19,184	18,552	103.41%	− 632
May	17,809	18,445	96.55%	+ 636
June	16,261	16,070	101.19%	− 191
July	14,956	17,192	86.99%	+2,236
August	18,501	21,765	85.00%	+3,264
September	16,387	14,329	114.36%	−2,058
October	15,163	15,722	96.44%	− 559
November	15,360	12,608	121.83%	−2,752
December	14,217	14,394	98.77%	+ 177

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OCEANOGRAPHY IN NEW ZEALAND

By A. W. B. Powell and C. A. Fleming

I. Introduction

The years 1949 to 1953 have seen important advances in organization and performance of oceanographic work in New Zealand. A review of New Zealand oceanography presented in 1947 (Hefferd 1950, *Trans. Roy. Soc. N. Z.* 77 (5): 212–21) indicates the state of research just prior to the 7th Pacific Science Congress. The stimulus provided by the activities of the Oceanography Section of the 7th Congress in New Zealand in 1949 has undoubtedly contributed to the advances made since that date, which are documented by the bibliography of New Zealand Oceanography 1949–53, compiled by the N.Z. Oceanographic Committee and tabled with this report.

In October, 1949, on the arrival of the naval survey vessels, H.M.N.Z.S. Lachlan in New Zealand, her Commanding Officer, Commander J. M. Sharpey-Schaefer, R. N., offered to collect data and material for New Zealand scientists. To co-ordinate requests for data and distribution of material, an Interdepartmental Committee on Oceanography was formed, with representatives of Victoria University College, Dominion Museum, Marine Department, and Department of Scientific and Industrial Research. The Committee drew up a programme of sampling and observation, and supplied the ship with bottom samplers, containers, scientific log sheets, and arranged for analysis of water samples, distribution of collections, mechanical analysis and petrological examination of sediments, and perusal of echo-traces. In June, 1950, the Interdepartmental Committee pressed for the formation of a National Committee fully representative of the many New Zealand oceanographers attached to different institutions and departments, to act as a national body competent to speak for New Zealand in oceanographic matters.

A further stimulus to oceanography in this country was provided by the opportunities afforded for some deep sea investigations arising out of the visits of three oceanographic vessels—R.R.S. Discovery II (1950–51), H.M.S. Challenger (1951), and the Danish Research Ship Galathea (1951–1952).

The New Zealand National Committee on Oceanography (Secretary J. W. Brodie) was formed in September, 1950, as an advisory research committee of the Council of Scientific and Industrial Research, and has since operated in effecting liaison, sponsoring research projects, and in advising the New Zealand Government on oceanographic

matters. In the field of physical oceanography, the committee through its physical sub-committee, arranged for preparation of a bathymetric map of New Zealand seas, for the collection of continuous echo sounding profiles by naval vessels in New Zealand seas, particularly on voyages between New Zealand, Australia, and the outlying islands, and for "collector tracings" of all surveys to be available for scientific use. Visiting expeditions (R.R.S. Discovery II, H.M.S. Challenger, H.D.M.S. Galathea) co-operated by supplying the committee with physical data of local interest (soundings, temperatures, bottom samples, etc.). Also molluscan material was allocated to two local specialists for study and report. In general, the committee has effected liaison between New Zealand workers in oceanography by assembling news-sheets, library lists, and lists of vessels and equipment available for research work.

II. Physical (C. A. Fleming)

Hydrographic Surveys by H.M.N.Z.S. Lachlan

Since her arrival in 1949, H.M.N.Z.S. Lachlan has been engaged on hydrographic re-survey of New Zealand coasts. New charts have been prepared of Foveaux Strait, Cook Strait, Wellington, Bluff, Lyttelton, and Otago Harbours, Peterson Inlet, and the east coast between Banks Peninsula and Wellington. Echo sounding surveys have clearly delineated the position of the continental shelf-edge and have demonstrated the presence of submarine canyons in Cook Strait and off the east coast of the South Island near Otago Peninsula, Banks Peninsula, and the Marborough Coast. In 1950, Lieutenant Commander B. M. Bary, M.Sc., Ph.D., N.Z. Defence Scientific Corps, joined H.M.N.Z.S. Lachlan as biologist, and the ship was equipped with a laboratory and oceanographic gear. Mr. T. M. Skerman, M.Sc., Oceanographic Observatory, D.S.I.R., joined the ship when Lt. Commander Bary left to further his studies at the National Institute of Oceanography.

In the course of hydrographic surveys, H.M.N.Z.S. Lachlan undertakes routine observations of sea surface temperatures, obtains salinity samples, bathythermograph records, bottom samples (using a Worzel sampler supplied by Geological Survey) and plankton hauls. The resulting collections and data are distributed to New Zealand oceanographers by the "Lachlan" sub-committee of the Oceanographic Committee.

Oceanographic Observatory, D.S.I.R.

The Oceanographic Observatory, Wellington, was formed in 1949 and is now organized as a unit of the Geophysics Division of the Department of Scientific and Industrial Research for the study of hydrological conditions in the seas around New Zealand. The present staff

consists of three professional officers and two technicians. The observatory suffered a severe loss by the death in March, 1953, of Mr. W. M. Jones, M.Sc., (N.Z.) B.A. (Oxon.), Director. In his contribution to the development of physical oceanography in New Zealand, Mr. Jones brought his long experience as a mathematical physicist in other fields of geophysics.

An Admiralty wave recorder was installed at Greymouth, west coast of South Island, in 1950, and ocean wave records obtained during a three-month period. An examination of these records in conjunction with weather information showed that there was satisfactory agreement between the main features of meteorological situations and the resultant wave spectra, and some graphical methods were evolved for evaluating the quantitative relations. The statistical relationships between the observed sea surface and its spectrum have been studied. Some results have been published by Jessie K. A. Watters (1953, "Distribution of height in ocean waves." *N. Z. J. Sci. Tech.* B 34: 408–22), and others will be published in a paper in preparation for the same journal by N. F. Barber, and R. A. Wooding ("Some statistical features of sea waves").

The sea surface temperatures obtained from 1949 to 1952 from merchant and naval ships and from surface recording thermographs installed on trans-Tasman and other vessels have been plotted on monthly charts as the basis for study of the surface hydrology of the southwest Pacific by D. M. Garner (who has submitted a short account of the results to this Congress). 1,600 salinity determinations, by the Dominion Laboratory (Wellington), are used to supplement the temperature data.

The hurricane at Suva in January, 1952, produced a microseismic storm on the Milne Shaw seismograph, and the relations of the microseisms to the position and intensity of the hurricane have been examined.

Geophysics Division, D.S.I.R.

Mr. J. W. Brodie has undertaken the filing and analysis of sounding records received from ships of the Royal New Zealand Navy and from other sources (including Discovery II, H.M.S. Challenger, and H.D.M.S. Galathea). An account of the sea floor west of New Zealand appears in *N.Z. J. Sci. Tech.* B 33 (5): 373–84, 1952. Contoured bathymetric charts of Cook Strait, Bay of Plenty, and Wellington Harbour have been compiled and a description of a seamount rising from 1000 to 5000 fathoms, west of Waikato Heads, has been prepared. 12,000 drift cards have been obtained for release during 1953 in the southwest Pacific to determine current movements.

Echo sounding profiles across the New Zealand continental shelf are being accumulated for study. Many profiles show the shelf to be terraced. The resurvey of Cook Strait by H.M.N.Z.S. Lachlan has shown that a submarine canyon drains southward from the relatively shallow (50-fathom) shelf of the western strait to depths in excess of 1,100 fathoms south of Cape Palliser. Shallow tributary channels crossing the shelf between Nelson and Taranaki bear no relation to the mouths of rivers. The resurvey has shown changes in the walls of the Cook Strait Canyon since the early surveys of last century.

During 1950, D. J. Banwell and B. H. Olson measured electric potential differences between points on shore spaced 2–3 kilometres apart, considered due to tidal currents (Couper, 1953, *Rep. 7th N.Z. Sci. Congr.* 3). Previous measurements (e.g. by Barber) were made in the northern hemisphere. The results agreed fairly well with the theoretical argument of Longuet-Higgins, given the opposite polarity of the earth's field.

New Zealand Geological Survey

Echo sounding and other bathymetric records were filed at the Geological Survey from 1949 until 1952 when the Geophysics Division undertook their custody.

The topography and sediment of Mernoo Bank, an oval elevation of the sea bottom rising from depths greater than 200 fathoms to 28 fathoms, 90 miles east of Canterbury, were described by Fleming and Reed (1951, *N.Z. J. Sci. Tech.* B 32 (6): 18–30) on the basis of an echo sounding survey by H.M.N.Z.S. Lachlan, and serial magnetometer profile and sediment samples. The bank is interpreted as a tectonic dome, composed of late Paleozoic to early Mesozoic indurated sediment, sculptured by shallow radial submarine valleys. J. J. Reed has studied the grain-size, sorting, and mineralogy of sediments of the Sumner estuary, Canterbury (1951, *N.Z. J. Sci. Tech.* B 33 (2): 129–37). From the Chatham Rise west of the Chatham Islands, R.R.S. Discovery II dredged coarse sediment at a depth of 170 fathoms containing pebbles of schist and of phosphatised Miocene globigerine limestone (Reed and Hornibrook, 1952, *N.Z. J. Sci. Tech.* B 34 (3): 173–88). Reed has prepared a sediment map of Cook Strait based on mechanical analysis of 170 samples, mostly collected with a Worzel sampler from H.M.N.Z.S. Lachlan. Few samples had been obtained from the floor of the Cook Strait Canyon, but the general pattern indicates that sediment is coarse near the canyon and fine on flat shelf areas distant from it. Calcite and siderite concretions, some of them fossiliferous, a foot or two in diameter, are regularly caught on fishing lines on the sides of the canyon and have been studied by C. A. Fleming. The concretions contain fossils pro-

bably of Pleistocene age and are bored by marine animals and support a vigorous epifauna. These facts suggest that an area of geologically young sediments is being destroyed by bottom scour on the sides of the Cook Strait Canyon, leaving the more resistant concretion on the sea bottom, where currents are sufficient (in depths of 100 to 120 fathoms) to prevent sediment accumulating.

B. L. Wood and I. McKellar (Geological Survey, Invercargill) have begun a study of bottom topography and sediment in Foveaux Strait off the East Coast of Otago. A submarine lignite from Foveaux Strait has been shown by pollen analysis to be Plio-Pleistocene in age, and to represent a cool climate (Couper, *N.Z. J. Sci. Tech.* B 33 (3): 178–86).

By arrangement with the Galathea Expedition authorities R. A. Couper is working on the spores and pollen grains in a sediment core obtained by H.D.M.S. Galathea in Milford Sound. Preliminary results suggest that it may be possible to determine the rate of sedimentation in the glacially over-deepened basin with the rock bar near the entrance to the sound owing to the appearance of pollen from introduced *Cupressus* trees at the top of the core.

Some further information on the White Island Trench, described by Fleming at the 7th Pacific Science Congress (1953, *Proc. 7th Pacific Sci. Congr.* 3:210–12), is now available as the result of echo sounding and a gravimetric survey. The trench, which is interpreted as the submarine continuation of the Rangitaiki Graben, has now been traced north eastward into the Bay of Plenty to depths in excess of 1300 fathoms, and additional work has shown that a parallel depression runs seaward on its west side, defining the ridge on which stands the White Island volcano. Gravity surveys of the Bay of Plenty have shown that the landward part of the trench is an area of negative anomaly, with a maximum difference of 50 milligals between the trench and the uplifted blocks which bound it on either side. Neither the gravity profiles, nor the echo traces are evidence that the depression has particularly steep walls, although these have been mapped geologically as faulty. The bottom relief offshore corresponds in detail with the gravity profile along the coast.

III. Biological (A. W. B. Powell)

A considerable amount of work that may be classified under the heading of biological oceanography is at present in progress at the several University Colleges, Museums and other scientific institutions in this country and an outline of the nature and scope of this work follows:

Although many of the titles in the Oceanographic Committee's bibliography and many of the topics included in my list work in progress suggest specialized zoological and botanical scope rather than oceanographic, it should be conceded that New Zealand is a young country and that the systematics and biology of many groups are still inadequately known.

All such papers collectively will eventually form an indispensable background for future biological oceanographic investigation.

Published Biological Work

The published papers are representative of most phyla but molluscan and algal studies predominate with 33 titles for the former and 16 for the latter.

Protozoa. Two papers by B. N. Bary on Sea-water discoloration.

Porifera. One paper, The Kirk Collection of Sponges, by H. B. Fell.

Coelenterata. Two papers on Ctenophores from Cook Strait by P. M. Ralph and C. Kabery and The Actinaria of New Zealand by G. Parry, which includes a check-list of recorded and new species.

Echinoderma. Five papers by H. B. Fell: "The Constitution and Relations of the New Zealand Echinoderm Fauna," "Echinoderms from Southern New Zealand," "The Occurrence of Australian Echinoids in New Zealand Waters," and several papers on littoral and deep-sea ophiuroids. Also a paper on Holothuria by W. H. Dawbin.

Polyzoa. A monograph of Tertiary Cheilostomata by D. A. Brown and two papers by G. H. Uttley contain many references to the systematics and distribution of recent species.

Mollusca. Thirty-three papers by C. Borland, R. K. Dell, C. A. Fleming, J. E. Morton, R. M. Cassie, Rapson, and A. W. B. Powell. In addition to systematics there are papers on life-histories, feeding mechanisms, animal communities of the sea bottom, population studies, biogeographic provinces, bipolarity and the dispersal of southern high latitude species.

Crustacea. Three papers on the Spiny Crayfish (*Jasus lalandi*) by C. A. Bradstock, two on brachyura by L. R. Richardson, one on new species of *Scyllarus* and *Ctenocheles* by A. W. B. Powell, and one on Amphipoda by D. E. Hurley. N. de B. Hornibrook has described "A new Family of Living Ostracoda with Resemblances to some Palaeozoic Beyrichiidae" and has published a monograph "Tertiary and Recent Marine Ostracoda of New Zealand, their Origin, Affinities and Distribution," including a systematic revision of the Cytheriidae.

Protochordata. Eight papers on New Zealand Ascidians by B. Brewin.

Pisces. Five papers by J. A. F. Garrick, J. M. Moreland, W. J. Phillips, and L. R. Richardson.

Mammalia. Southern Ocean Seals, two papers by E. G. Turbott and the "Elephant Seals of Campbell Island" by J. H. Sorensen.

The algal papers deal with systematics, ecology, zonation and algal provinces. The authors are M. P. Ambler, J. A. Carnahan, V. J. Chapman, R. F. de Berg, U. V. Dellow, and V. W. Lindauer.

Biological Work in Progress in New Zealand

FISHERIES BRANCH, MARINE DEPARTMENT, WELLINGTON.

Survey of Snapper (*Pagrosomus auratus*) spawning grounds in the Hauraki Gulf, Auckland, to log the distribution and density of eggs and larvae.

Routine trawls in the Hauraki Gulf to record the seasonal variation in the composition of fish stocks.

Investigation of the spawning areas for Tarakihi (*Dactylopagrus macropterus*) in the Gisborne-East Cape area.

VICTORIA UNIVERSITY COLLEGE, WELLINGTON.

The Zoology Department is encouraging students to specialize in the systematics of groups. In recent years students of the Department have investigated Amphipoda, Cephalopoda, Macrozooplankton and Ostracoda. Staff members are at present working on Coelenterata, Hirudinea, Crustacea Brachyura, Echinodermata and Pisces. A study is in progress also on optimum and lethal points of environmental factors for marine larval organisms. In addition an investigation of the Cook Strait Whaling Industry and the ecology of the humpback is continuing.

DOMINION MUSEUM, WELLINGTON.

A survey of marine bottom communities in Wellington Harbour and Cook Strait. The compilation of a molluscan check-list for the Cookian Province. R. K. Dell.

The Relationships of the Kermadec Mollusca (paper for the Eighth Pacific Science Congress) R. K. Dell.

A revision of the shore fishes of New Zealand. J. Moreland.

AUCKLAND UNIVERSITY COLLEGE.

In the Botany Department three papers are in progress. A continuation of the study of the mangrove and salt marshes in New Zealand, by Professor V. J. Chapman.

Study of life history and taxonomy of certain red algae, in particular *Porphyra, Lomentaria* and *Apophloca,* by Miss Jane M. Trevarthen. A study of the factors determining the occurrence and distribu-

tion of *Hormosira banksii,* including especially a determination of the depth in sea water at which the compensation point is reached, by Mr. C. B. Trevarthen.

AUCKLAND INSTITUTE AND MUSEUM.

A report entitled "Mollusca of the Cape Expedition" is now finished and awaits publication. It is primarily a report on the molluscan collections made during 1941–45 by personnel of the coast-watching stations, but all previous molluscan records for the Southern Islands of New Zealand are listed and evaluated. Forty-three new species are described and the area is oriented into three marine provinces.

Other reports in progress are (1) Mollusca of the BANZARE expeditions (Macquarie, Kerguelen, Heard Islands and Antarctica, (2) Gastropoda from the Galathea Expedition, (3) Benthic Molluscan faunules from Hauraki Gulf, Bay of Plenty and Northland; ecological and a correlation between animal communities and bottom textures. A. W. B. Powell.

Distribution study of the Red-billed gull by ringing at Three Kings Islands. Field studies of sea birds during M.V. "Alert" expedition to Antipodes and Bounty Islands in 1949. E. G. Turbott.

UNIVERSITY OF OTAGO.

In the Department of Zoology the following two papers of oceanographic interest are in progress:

Systematics and geographical distribution of New Zealand Ascidians and the development, growth and life history of a local highly-specialized compound ascidian, by Miss B. Brewin.

Systematics and geographical distribution of New Zealand sponges, by Mrs. S. Rind.

PORTOBELLO MARINE BIOLOGICAL STATION.

Amphipod systematics; wharf pile fauna studies in Otago Harbour; Ecology of crustacea and other bottom dwelling animals, by D. E. Hurley.

Neuromuscular system and behaviour of Coelenterates; Intertidal ecology, by Dr. E. Batham.

CANTERBURY UNIVERSITY COLLEGE, CHRISTCHURCH.

Mr. G. A. Knox has commenced a bottom sampling programme on the continental shelf of Pegasus Bay and off Banks Peninsula. The work will form the basis for a study of the relationship of the bottom communities and the feeding habits of fishes. He is continuing work on the Systematics of New Zealand Polychaetes and on the intertidal ecology of New Zealand rocky shores. Miss F. R. Nurse is engaged on studies in New Zealand and Macquarie Island Turbellaria. Dr. R. L.

Pilgrim has begun a revision of New Zealand Nudibranchia, and Professor E. Percival is working out the life history of *Tegulorhynchia nigricans* as part of his general interest in brachiopoda in New Zealand tidal waters.

NEW ZEALAND GEOLOGICAL SURVEY.

Mr. N. de B. Hornibrook continues study of marine Ostracoda and Foraminifera, particularly Globigerinidae, which may be useful paleotemperature indicators. Mr. P. Vella has completed a survey of the Foraminifera of Cook Straits.

SUMMARY OF OCEANOGRAPHIC WORK CONDUCTED BY THE PACIFIC OCEANIC FISHERY INVESTIGATIONS SINCE 1949

Objectives:

To survey the distribution of physical, chemical and biological properties of the waters of the central equatorial Pacific and to combine the resultant oceanographic data with those from the experimental fishing operations in an effort to better understand the particular ecological situations in which the fish are present or absent.

Facilities:

The major portion of the oceanographic survey program has been carried out aboard the *Hugh M. Smith,* a former Navy YP of the 600 class. The *Smith* is 128 feet long with a beam of 29 feet; is powered with a 560 H.P. Union Diesel and has a cruising range of 8,500 miles. The present oceanographic equipment includes two winches for raising and lowering Nansen bottles and for towing plankton nets; a bathythermograph installation; and automatic surface temperature recorder, and a GEK (Geomagnetic Electrokinetograph) for recording velocities of surface currents.

An oceanographic and biological laboratory is located on the main deck where chemical analysis are made and where biological specimens studied and preserved.

The *John R. Manning,* west coast purse seiner, and the *Charles H. Gilbert,* a combination tuna boat and longline vessel, are both equipped with recording thermographs and with bathythermograph installations. Plans for a biological-oceanographic laboratory aboard the *Gilbert* are presently nearing completion.

Laboratory and office space are available in the POFI building located on the campus of the University of Hawaii. A calibration tank for reversing thermometers and limited shop facilities are also provided.

Programs:

Since 1949, a total of 13 oceanographic survey cruises have been conducted, 8 in the equatorial area and 5 in the Hawaiian Island waters. On all cruises, continuous records of surface temperature and data from bathythermograph lowerings at frequent intervals are available. Continuous records of surface temperature and those from less frequent bathythermograph lowerings are available from 13 exploratory fishery cruises in the equatorial region and 19 in the Hawaiian area.

In general, each oceanographic station consisted of thirteen samples, surface to 1,000 meters. Protected and unprotected reversing thermometers were used with the Nansen bottles. Samples were drawn from each depth for chlorinity and phosphate analysis. A 900-foot bathythermograph record and associated meteorological observations were included with each station.

Current measurements were made by all practicable methods including the drift of the vessel; drift of the nets or longline when available and by actual measurements of surface currents with the GEK. On one cruise, Cruise 16 of the *Smith,* shallow and deep drags were used.

Navigational methods include the dead reckoning plot with positions fixed by astronomical sights, Loran and, when practicable, by radar.

Results:

Analyses of the data from the cruises in the equatorial region, 10°N. to 10°S. latitudes between 140° and 180°W. longitudes, have yielded a better understanding of the equatorial circulation within this area. Summaries of the POFI oceanographic cruises, including discussion and tabulation of the station data, are being published in the special scientific reports of the Fish and Wildlife Service, U.S. Department of the Interior. The first such report, *Mid-Pacific Oceanography, January-March 1950,* by Townsend Cromwell, was issued in July as SSR No. 54. In addition, Mr. Cromwell has submitted for publication a theoretical consideration of equatorial circulation entitled *Circulation in a Meridional Plane in the Central Equatorial Pacific.* Some of the results of these and other studies presently underway are:

In general, the circulation pattern consists of the westerly moving North and South Equatorial Currents, with the relatively narrow counter-current between. The northern and southern limits of this counter-current are about 10° and 5°N. respectively. In addition to these surface currents, there is evidence of a sub-surface counter-current centered at the Equator, beneath the South Equatorial Current. Al-

though as yet little understood, this subsurface counter-current may have considerable significance with respect to the biology of the area.

The only upwelling of significance is centered at or slightly south of the Equator. The intensity of this upwelling, as reflected by lower surface temperature, decreases from east (120°W.) to west (180°). Data from Japanese surveys indicate very little upwelling west of 170°E. longitude. The upwelled water, characterized by lower temperature and high phosphates, usually has a northerly movement from the point of origin. The surface movement may be suddenly checked by convergence and sinking. This convergence may take the form of a front with a *sudden* change of several degrees in surface temperature, or may be reflected as a more *gradual* change through a zone of transition. In either case, phosphates and zooplankton also usually change, i.e., a decrease in concentration of PO_4 and in zooplankton volume when crossing from the southerly colder water into the warmer waters of the South Equatorial Current.

Data presently at hand permit only generalizations concerning this circulation pattern. Information concerning short period and seasonal fluctuations in the circulation will require additional surveys, these surveys planned to delimit these changes both in space and in time.

There are not, as yet, sufficient oceanographic data in the Hawaiian waters to permit even a generalization concerning the circulation or related conditions. This program has been considerably augmented and within six months to a year considerable information will be forthcoming.

A BRIEF REPORT ON OCEANOGRAPHIC RESEARCH IN THE PHILIPPINES

By D. V. Villadolid

The oceanographic work now in progress is actually a continuation of some phases of the investigations conducted in 1947–50 by the United States Fish and Wildlife Service under the Philippine Fishery Program. Following the termination of its operation in June, 1950, the U.S. Agency turned over to the Bureau of Fisheries the M/V "David Starr Jordan" along with a batch of oceanographic gear and supplies. The boat is a 30-ton otter trawler driven by a 135-hp Murphy full diesel engine, giving a cruising speed of six knots. The principal dimensions of the boat are: Length overall, 16.2 meters; length at water line, 14.6 meters; breadth, 4.0 meters; and draft, 2.0 meters. A portable laboratory was installed on the afterdeck.

Survey work currently assigned to the boat is confined to sheltered coastal areas, the seats of the principal fisheries of the Philippines. Water samples are collected at different standard levels and measurements of temperature, chlorinity and nutrient salts contents are taken. Subsurface plankton hauls are occasionally made, but surface plankton tows are a regular part of the hydrographic work.

Of the five areas surveyed since the work commenced in February, 1951, Manila Bay in Luzon Island has been the most comprehensively studied. The area was visited every month for one year, occupying a total of fifteen stations whenever weather conditions permitted. A total of 3,115 measurements of physical and chemical properties of the waters of Manila Bay were taken during the year's survey. Processing of the data has already been completed and a report on the inter-relationships between the physical and chemical parameters and the external factors affecting them is forthcoming.

For the purpose of determining long range variations in the properties of the waters fringing the island archipelago, we have established a number of fixed collection stations ashore at strategic places in the Philippines. At this writing we have one on the Pacific side and two on the South China Sea side. It is our intention to increase the number of these collection stations later on. In this type of work only surface samples are collected at a fixed hour daily and measurements of temperature and chlorinity are taken. In addition, hourly measurements in a 24-hour cycle are made twice a month at each station.

In cooperation with the Philippine Weather Bureau, our oceanographic staff is charged with the processing of observational data turned in to the Weather Bureau by ocean going liners. Water and air temperatures form the principal part of these data.

OCEANOGRAPHIC ACTIVITIES IN SOUTH AMERICA

By B. F. Osorio-Tafall

ECUADOR

In 1951 FAO sent on request a Fisheries Biologist to make a brief survey of the sea fisheries in the territorial waters of Ecuador. The expert conducted concurrently fishery research work, oceanographic and meteorological observations including collection of sea-surface temperatures, not only along the continental coast, but also in the waters of the Galapagos Islands, and on his way hence and back between the continent and these islands.

Due to adverse conditions, the expert of FAO was not able to complete the brief oceanographical survey, as planned, but was able, on his last voyage to the Galapagos Archipelago, to take some hydrometer readings in correlation with the sea-surface temperature.

The results of these observations will be published soon by FAO in the form of a report.

Ecuadorean biologists which attended the Latin American Fisheries Training Centre, held in Valparaiso in 1952 will probably continue the investigation initiated by the FAO expert.

PERU

Scientific investigations with regard to the Peruvian Current are undertaken in Peru by the Department of Fish and Game (Direccion de Pesca y Caza) of the Ministry of Agriculture in Lima, by the Hydrographic and Lighthouse Service (Servicio Hidrografico y de Faros) of the Peruvian Navy, and by the Company for the Administration of Guano (Compania Administradora del Guano).

The investigations of the Department of Fish and Games refer mainly to studies of the biology of commercially important species of fish, conducted at a laboratory installed at the fishing terminal in the port of Callao.

The studies of the Hydrographic Service of the Navy are at their beginning. They shall encompass the investigation of some problems in which the Navy is interested and a general oceanographical research agreed upon with the Company for the Administration of Guano which, however, has not yet been started.

This company is studying the basic ecological conditions of the habits of guano birds and has, therefore, initiated the collection of Oceanographic and Meteorological data including sea-surface temperatures since 1939. Special studies of plankton and the life cycle of the anchovy, which is the basic food of guano birds, and the investigations of the populations of important food fishes as well as aquatic mammals found in Peruvian waters are also being carried on.

As a result of these activities the Guano Company has published already the first part of an Atlas of the Coastal Current of Peru (Atlas de la Corriente Costanera Peruana) and a series of Monthly Maps of the Peruvian littoral with indications of the average sea-surface temperature, air temperature, barometric pressure and wind, direction and force, for the years 1946 to 1951 (published during 1952), and is presently editing a new set of monthly maps containing the same data for the 14 years between 1939 and 1952, which also indicate the trends for the year 1953.

For these purposes the Guano Company installed a central department of Oceanography and Ichthyology in their head office at Lima from which depend three biological stations, one occupied with investigations of the normal and abnormal behavior of birds, another one which has been mainly studying for four years the variations and development of plankton, and a third one occupied mainly with the study of the biology and life cycle of the anchovy. The outcomes of these investigations shall be published twice a year in a special bulletin entitled "Scientific Bulletin of the Company for the Administration of Guano" (Boletín Científico de la Compañía Administradora del Guano). The first issue is already in print.

Scientific oceanographic expeditions have worked in Peru in 1952 and 1953, in collaboration with the Guano Company and the Hydrographic Service of the Navy. In 1952 Peru was visited by the "Shellback Expedition" of the Scripps Institution of Oceanography which carried on her way to Callao one employee of the Guano Company and from Callao to Puntarenas, Costa Rica, two other employees of the same company. A special boat of the Navy of Peru made, during the same time, cruises on zones beforehand appointed.

In 1953 the "Yasa" expedition of Yale University came to Peru, which worked with the representative of the Hydrographical Service of the Navy and the Guano Company.

Educational work on oceanography is at its beginning. The Geographic Institute of the University of San Marcos, Lima, has just started a series of lectures on oceanography applied to Peru. The students are mainly graduates of that same Institute and they work mostly as teachers in Peruvian public schools. It is hoped that the number of general lectures on the influence of the sea in Peru and in the human activities on its coast will be steadily increasing.

CHILE

Pure oceanographic research has not been conducted to any significant extent by Chilean investigators. Their tendency has been to study the sea as the habitat of organisms of commercial importance. In view of this, the FAO Fisheries expert, Dr. Erick Poulsen, made some observations of temperature down to 80 meters, as a complement of his study of the populations of hake in the coast of Chile.

Another FAO expert, Dr. Fernando de Buen, during his investigations of the biology of pelagic fishes of commercial value which habits are very much influenced by oceanographical changes, made observations of temperature and salinity at different depths, in 15 stations. He also collected samples of plankton in meritic and oceanic waters.

He worked in sub-antarctic waters which reach north in Chile, as well as in a warm strip found above the cold waters, through which some species of commercial importance like the yellow fin tuna and the skipjack reach the northern fishing ports of this country.

The Chilean merchant boats and Navy vessels are constantly taking surface temperature along the coast which are collated by the Hydrographic Office and sent to the Division of Fish and Game. This material has been recently handed over to the FAO Regional Office in Santiago where it is being compiled and plotted in charts.

The Marine Biological Station of Montemar of the University of Chile has conducted some oceanographic observations including the determination of dissolved oxygen.

The University of Concepcion in Southern Central Chile operates a Marine Biology Station devoted principally to the study of local marine communities.

The Chilean Navy, once a year during the Summer season (January), sends an expedition to the Antarctic territories claimed to belong to Chile in order to relieve the personnel and supply three land bases operated respectively by the Army, the Navy and the Air Force.

One or more scientists are assigned to each expedition. They are instrumental in collecting information on hydrographical condition as well as in making collection in the Antarctic waters. Also there is a yearly expedition to Easter Island which gives the opportunity for scientific collections in Juan Fernandez, San Felix and San Ambrosio islands. Routine observations of temperature and plankton collections are made.

Regional Meeting of Food and Agriculture Organization of the United Nations

During the Second Regional Meeting of FAO held in Montevideo, Uruguay, from 1 to 12 December, 1952, three resolutions were passed recommending: (1) the organization of a Latin American Fisheries Council; (2) establishment of a Latin American Fisheries Training Centre to prepare fisheries workers in fisheries administration and research; and (3) operation of a research centre for the study of the Humboldt and El Niño Currents.

1. *Latin American Fisheries Council.*

One of the items of the programme of work of FAO is to organize regional fisheries councils in areas where governments need help for the development and coordination of fisheries administration and research. Two Councils have already been organized and have been in

operation for a number of years: the Indo-Pacific Fisheries Council and the General Fisheries Council for the Mediterranean.

Following the resolution of the Second Regional Meeting of FAO it was proposed to the Fifth Session of the Conference of the same organization by its Director-General, that a Fisheries Council should be also established in Latin America to help coordinate the efforts of the countries of the region to further study and develop their fisheries.

Accordingly an organizational meeting took place in Lima, Peru, in September, 1951, during which 15 countries reached an agreement to establish a council. This agreement has been approved by the Sixth Session of the FAO Conference and submitted to the interested governments for ratification. As soon as five Member Countries of FAO in the area accept the agreement, the Council will come into existence. The FAO Regional Fisheries Office for Latin America will act as the secretariat.

2. *Latin American Fisheries Training Centre.*

The lack of trained personnel in fishery administration and fishery research in general is a great obstacle in the development and study of the fishery resources of the world. This situation is particularly acute in Latin America. To help solve this problem, FAO in accordance with the recommendations of the Montevideo Meeting, operated in Valparaiso, Chile, a training centre for fisheries workers of the region which lasted from 6 January to 14 March, 1952.

About 50 delegates and observers from 7 countries attended the classes given, which covered the fields of fishery administration, biology, technology, and economics.

The following courses were given by the listed instructors: Dr. Jorge Ahumada (ECLA-UN), Appraisal of Fisheries Projects; Jorge Alarcao, (FAO), Fisheries Statistics; Richard S. Croker (U.S.A.), Fisheries Administration; Dr. Fernando de Buen (Uruguay), Economically Important Families of Fishes; Dr. Carlos Gonzales (Argentina), Sanitation of Fishery Products; Mogens Jul (FAO), Handling and Refrigeration of Fisheries Products; Antonio Landa (Peru), Analytical Biological Fisheries Statistics; Milton J. Lobell (Chile), Fishing Methods, Craft and Gear; Dr. Antonio Lopez-Matas (Chile), Canning and Curing of Fish, Fish by-products; Dr. B. F. Osorio-Tafall (FAO), Latin American Fisheries, the Living Aquatic Resources and Their Importance for Man; John C. Marr (U.S.A.), Marine Fisheries Management; Valentin Paz Andrado (Spain), Fisheries Economics; Felipe Quezada (UN), Economic Geography of Latin America; Dr. Gerardo H. Schwabe (Chile), Molluscs and Crustaceans of Commercial Importance; Dr. Erwin

Schweigger (Peru), Elements of Oceanography; Dr. Rui Simoes de Menezes (Brazil), Utilization of Fresh Water Fisheries Resources; Sven Somme (Norway), Fisheries Extension Service; Dr. Parmenio Yanez (Chile), Introduction to Fisheries Literature.

Special lectures and seminars were also given by the following instructors: Dr. Edward Kotok (FAO), Dr. Erik Poulsen (Denmark), Dr. Robert Smith (U.S.A.), Dr. Arturo Vergara (FAO), Dr. Julio Luna, F. Jimenez Cesneros, A. Rendic and Dr. Edwyn Reed (all of Chile).

Some of the courses given are now being edited to be reproduced in book form.

3. *Study of the Humboldt and El Niño Currents.*

The cold Humboldt Current as well as the warm countercurrent of El Niño, has a strong effect in the distribution of the fishery resources as well as the climate of the coast of Western South America. It is thought, therefore, that there is a great need for a long term study of the oceanographic and meteorologic conditions of the region to help its fishing, agriculture and livestock industries.

During the above mentioned meeting in Montevideo, it was urged that international institutions should work out a way of organizing an international centre to conduct these studies which are of such importance for the region.

FAO and the Centre of Scientific Cooperation of the UNESCO for Latin America are presently studying the ways and means of organizing an International Network of Marine Biological Laboratories in Latin America. The establishment of International laboratories in the Pacific and Atlantic coasts of South America are under consideration. It is expected that the laboratory of the Pacific coast will conduct the recommended studies of the Humboldt and El Niño Currents.

Organization of an International Network of Marine Biological Laboratories in Latin America.

On 1 and 2 August 1952, the Centre of Scientific Cooperation of the UNESCO for Latin America held a meeting in Montevideo, Uruguay, attended by the Advisory Committee on Scientific Regional Laboratories of Latin America to study the possibilities of organizing "Regional Scientific Laboratories." Along with the other resolutions passed in this meeting it was recommended that the possibilities of organizing international marine biological laboratories in the region should be studied as soon as possible. These laboratories are supposed to conduct research and courses in marine biology, oceanography, fishery biology and related subjects.

UNESCO has extended an invitation to FAO to cooperate in this project. It is planned to hold a meeting in 1953 of experts in the field to discuss the problems and possibilities of organizing the laboratories in question.

PACIFIC OCEANOGRAPHY IN THE UNITED STATES

By Thomas G. Thompson

NATIONAL ACADEMY OF SCIENCES

In 1949 the National Academy of Sciences established a special committee to review the resources in facilities, personnel and income available in the United States for the support of oceanographic research and to discuss some of the difficulties which must be overcome to assure the advancement of the science. A report of this committee was published in 1951 as Publication No. 208 of the National Academy-National Research Council. The report deals, in a general manner, with recent accomplishments in basic oceanographic research, applications of oceanography in peace and war, current problems in developing oceanography in the United States and present facilities available for oceanographic investigations.

U.S. NAVY HYDROGRAPHIC OFFICE

The Hydrographic Office has continued to collect bathythermograph observations made by naval vessels and Coast Guard Station vessels in the Pacific. Routine current reports have been obtained from the navigators of merchant vessels in the Pacific and added to the file that the Hydrographic Office has been assembling for many years. Records of drift bottles have also been collected and notes concerning them have been published in the Hydrographic Bulletin. In addition, a survey of coastal waters of the United States is being carried on under contract by various scientific institutions among which are the University of California and the University of Washington.

U.S. COAST AND GEODETIC SURVEY

In the United States and Alaska, tide stations were continued in operation as follows: 18 along the Pacific coast of the United States and 11 in Alaska. In continuing the program of tidal investigation in the Pacific Islands area, tide stations are being maintained at 14 locations: 6 in the Hawaiian area, 1 at Wake Island, 2 in the Marshalls area, 1 in the Marianas area, 2 in the Carolines area, 1 in the Samoan area, and 1 in the Phoenix area. In addition, records are being pro-

cessed from 13 stations maintained in the Pacific area of Latin America by the Inter-American Geodetic Survey.

The tidal observers at most of these stations also made a daily observation of sea water temperature and density. The results are published in Special Publication 280 (formerly TW–2), "Surface Water Temperature, Pacific Coast," and in Special Publication 281 (formerly DW–2), "Density of Sea Water, Pacific Ocean."

During the course of hydrographic surveys in Alaskan waters, Coast and Geodetic Survey ships have made serial observations of temperature and density for use in the surveys, and also made several series of bathythermograph observations for the U.S. Navy Hydrographic Office.

There have been a number of seismic sea waves recorded by Coast and Geodetic Survey tide gages during the last few years, the largest and most notable being the tsunami of November 4, 1952. A report of this tsunami is in preparation and should soon be available in printed form.

CALIFORNIA ACADEMY OF SCIENCES (Prepared by ROBERT C. MILLER)

In the summer of 1949, the California Academy of Sciences, under contract with the Office of Naval Research, undertook an exploration of the geology of the continental shelf and slope off central California. The net tender U.S.S. *Mulberry* was assigned to this project. It was an extremely suitable vessel because it carried heavy cables and powerful winches. Much of the work consisted simply of breaking off pieces of rock from the sea bottom.

Seven members of the Academy's staff participated in the operations at sea, and 66 collecting stations were occupied before international events required the reassignment of the *Mulberry* to other duties. Through the cooperation of the United States Coast Guard and the California Department of Fish and Game, the project was continued and brought to a successful termination.

The geology of the Farallon Islands, not heretofore known, was worked out in considerable detail. A study was made of three seamounts, the Guide, the Pioneer, and a third which was named the Mulberry. On the Guide seamount no rock outcrops were found, the dredge bringing up only mud. On the Pioneer seamount several hundred pounds of basaltic material was obtained. It contains titaniferous augite and in this respect differs from volcanic material in the adjacent coastal mountain ranges. The Mulberry seamount is also volcanic, and the rocks have a "fresh" appearance. While these seamounts have no doubt come up through volcanic action, evidence was obtained of a fairly recent subsidence of the continental shelf.

In the course of dredging for geological materials, large numbers of biological specimens were also obtained, which have been described by specialists. The results of this work have been published chiefly in the Proceedings of the California Academy of Sciences, Fourth Series, Volume 27, Nos. 9–16.

HOPKINS MARINE STATION (By Rolf L. Bolin)

An investigation of the fluctuations in the populations of marine organisms correlated with fluctuations in hydrographic factors was initiated in 1950 under an Office of Marine Research contract. A shallow water oceanographic station, extending to 30 meters in Monterey Bay and a deep-water station, extending to 1000 meters in the waters off Monterey Bay are being occupied at weekly intervals. Temperature, salinity, oxygen, phosphate, silicate, and light penetration data, and plankton samples from both surface layers and deep waters are being collected. Until the present time more than 300 stations have been occupied, more than 20,000 physical observations and chemical determinations, have been made, and the analysis of the plankton samples and their correlation with hydrographic fluctuations is in progress.

OCEANOGRAPHY BRANCH OF THE NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA

Research has continued in physical oceanography, underwater sound, and sea floor structure. The main emphasis has been directed toward the temperature structure of the ocean and upon the relation of sound transmission to physical properties of the sea. Much work has also been done in the field of marine geology, especially regarding sea floor processes and interpreting sea floor structure from echo sounding profiles.

SCHOOL OF TROPICAL AND PREVENTIVE MEDICINE, LOMA LINDA, CALIFORNIA (Prepared by Bruce W. Halstead)

Since the inception of the School of Tropical and Preventive Medicine in 1948, the Department of Ichthyology and Herpetology, under the supervision of Dr. Bruce W. Halstead, has directed its efforts toward investigating the problem of poisonous fishes in the tropical Pacific. Field studies were conducted in the following areas during September, 1950, to July, 1953; Phoenix, Line, Hawaiian, Marianas, Eastern and Western Carolines, Johnston, Okinawa, Japan, Galapagos, Cocos, La Plata (Ecuador), Gulf of California, and Panama Bay. The investigations thus far have been concerned largely with the epidemiological aspects of the problem, viz., the specific identification of these fishes and compilation of data relative to their geographical distribution. All fishes brought into the laboratory are identified as to their

scientific names and then fresh samples are taken from the muscle, liver, intestine, intestinal contents, and gonads for toxicological analysis. Tissue extracts are prepared with the use of distilled water by homogenization and centrifugation. Four samples of each tissue extract of 1 ml. each are injected into four white mice (CC_1 strain) and observed for 36 hours for the development of toxic symptoms. Studies thus far indicate that the poisonous fish population of the tropical Pacific is much larger than was formerly believed. Toxic species, exclusive of plectognaths (Puffers, triggerfish, boxfish, porcupinefish), have been found to occur in the Pacific from the Galapagos Islands to the Philippines and Okinawa, and from Midway to Tahiti. The survey of Canton demonstrated that about 27 per cent of the reef fishes (largely from the lagoon) were toxic. The survey at Johnston Island indicated that about 69 per cent of the lagoon fishes were toxic. The studies of the other areas are in various stages of progress.

The problem of poisonous fishes represents one of the greatly neglected fields of medical and ichthyological research. Since fish poisoning, ichthyosarcotoxism, is not listed as one of the reportable diseases, there are no accurate data as to its incidence. The existing confusion and lack of precise data regarding the identity, geographic distribution and biology of toxic fishes, and the nature of ichthyosarcotoxins, can only result in hampering the economic development of the shore fisheries of the tropical Pacific. The fact that a fish species may be commercially valuable in one locality and violently toxic in another can be a major factor in outlawing otherwise valuable fishing grounds. A classical example of this very situation is the current poisonous fish problem in the Line Islands. On a number of occasions reef fishes such as snapper, grouper, seabass, ulua, etc., have been shipped into the Hawaiian fish markets and there has resulted serious outbreaks of fish poisoning. As a result of these epidemics all reef fishes from the Line Islands are banned from the Hawaiian markets. Future world demands for protein food sources will necessitate a more rigid control and efficient utilization of the vast food reserves of the ocean. The problem of poisonous marine organisms will become of increasing importance in the years to come.

UNIVERSITY OF CALIFORNIA–SCRIPPS INSTITUTION OF OCEANOGRAPHY

The Scripps Institution of Oceanography is divided for administrative purposes into several research divisions, with a number of supporting activities.

The research groups are the Bathythermograph, Chemical Oceanography, Marine Biochemistry, Marine Botany, Marine Invertebrates,

Marine Microbiology, Marine Genetics, Marine Vertebrates, Physical Oceanography, Waves and Currents, Descriptive Oceanography, Special Developments, Submarine Geology, Sediments, and Shore Processes Divisions, and the Foraminifera, Marine Physical, and Visibility Laboratories.

Supporting activities include the Library, Aquarium-Museum, Oceanographic Photography, and Oceanographic Publications.

Marine Life Research Program

Jointly with the California Department of Fish and Game, the U.S. Fish and Wildlife Service, the California Academy of Sciences, and the Hopkins Marine Station, Stanford University, the Institution participates in the California Cooperative Sardine Research Program. The Institution's share of this research endeavor is known as the Marine Life Program and has been supported since 1949 by the California Legislature.

The investigation has placed the greatest emphasis on studying the ecology of the California sardine including its food and life history. The study, however, involves basic research on other pelagic fishes, such as sauries, anchovies, and mackerel; on the pyto- and zooplankton; and on the chemical and physical factors operative in the environment. With only a few omissions, monthly cruises have been conducted along the coast of California and Baja California from San Francisco to Cape San Lucas and seaward to distances up to 350 miles. Three ocean-going vessels participate in each cruise.

University and Foundation Sponsored Research

There is more or less overlapping of problems with contract research. The following can, however, be specifically mentioned:

1. Comparative biochemical studies of marine animals and their environment. These have involved especially (a) kinds and biological significance of carotenoids, porphyrines, fluorescent pigments and other biochromes in marine animals, leptopel and buried sediments; (b) exchange of elements between organisms and the environment including plant nutrients, ionic iodine, vanadium, and calcium, using radioactive isotopes and tracers.

2. Microbiological research on (a) effect of hydrostatic pressure on bacteria to depths exceeding 7000 meters; (b) sulfate reducing bacteria; (c) fish diseases.

3. Nutritional studies on invertebrates, fishes, and seals.

4. Ecological, taxonomic and zoogeographical studies on certain pelagic invertebrates, deep-sea fishes, and littoral invertebrates.

5. Life histories of invertebrates and fishes.

6. Recently initiated research on marine genetics, utilizing paper chromatography.

Contract Sponsored Research

Contract work accounts for a considerable share of the research budget of the Institution.

Under contract with the Office of Naval Research, the Institution is engaged in a long-term program of basic research on ocean currents, gravity waves of a wide range of frequencies, the temperature and density structure of the ocean, submarine geology and geophysics, Arctic physical and biological oceanography, and aspects of underwater sound.

The Office of Naval Research also supports work on marine foraminifera, marine wood-boring organisms, non-visual methods by which fish detect obstacles, and the behavior of deep-sea microorganisms.

Under contract with the Office of Naval Research, the Bathythermograph Division processes all bathythermograms taken by Navy and oceanographic research vessels in the Pacific, and conducts research on bathythermogram data.

The Bureau of Ships for several years has supported investigations of marine physics and the development of oceanographic instrumentation and during the past year has, with the Air Force, supported a large-scale program concerned with marine optics.

Under contract with the Beach Erosion Board, there has been an extensive investigation of beach erosion processes, nearshore currents, and sedimentation.

The Air Force supports an investigation of the physics and chemistry of the air-sea boundary layer.

A study of nearshore recent sediments is supported by the American Petroleum Institute. Field work under this program is conducted on the Texas coast and in the east Mississippi Delta area.

A study of the fish life of the local kelp beds is conducted under a contract with the Kelco Company.

Expeditions

Since 1950 the Institution has conducted under Navy sponsorship four long expeditions into the Pacific. In 1950 the Mid-Pacific Expedition, carried out jointly with the U.S. Navy Electronics Laboratory, went to the Marshall Islands. In 1951, the Institution's vessel HORIZON travelled to the Gulf of Alaska on Northern Holiday Expedition. In 1952, HORIZON, as part of a large-scale cooperative venture known as Operation CO–OP, conducted the Shellback Expedition to Peru. In 1952–53, HORIZON and SPENCER F. BAIRD investigated the geology and

geophysics of the South Pacific on Capricorn Expedition. In all, Scripps Institution vessels have steamed approximately 76,300 miles in the course of these expeditions, exploring several parts and several aspects of the Pacific never studied before.

Physical Plant

In 1950, the Institution opened its Thomas Wayland Vaughan Aquarium-Museum. The building contains an aquarium in which are displayed species representative of the marine life of the La Jolla area, and a museum of oceanography. The Institution's administrative offices are temporarily located in this building. Since its opening the Aquarium-Museum has attracted approximately 3,000 visitors a week.

Construction is expected to begin within the next year on a four-story addition to the Institution's chief laboratory building, Ritter Hall. The new addition will contain laboratories and offices. In the planning stage is a large salt-water experimental aquarium.

In 1952 the Regents accepted the gift of several acres of natural marshland bordering on Mission Bay. A portion of this land may be used for research in marine ecology and marine plant and animal genetics.

Ship Facilities

The Institution now operates five vessels. These are SPENCER F. BAIRD (143 feet, 760 tons), HORIZON (143 feet, 760 tons), CREST (136 feet, 206 tons), PAOLINA T (80 feet, 3 inches, 110.67 tons), E. W. SCRIPPS (104 feet, 109 tons). In addition it operates two buoy boats, several skiffs, and an amphibious truck (DUKW).

Institute of Marine Resources

In 1952 the Regents approved the establishment on the La Jolla campus of an Institute of Marine Resources, which will "foster research, education, and public service by the University in the development of fisheries and other resources of the sea."

Educational

Enrollment since 1949 has averaged about 50 students per semester. Since 1949 the Regents have granted 41 degrees of Master of Science and 19 degrees of Doctor of Philosophy in Oceanography for work carried out at the Institution.

Personnel and Annual Research Budget

The Institution now has a research budget of approximately $1,500,000 per year. Since 1948, the number of staff members has increased from approximately 100 to 415. There are at present more than 100 persons engaged in research.

Publications

Since 1 January 1949 there have been 187 papers by staff members published in the scientific journals. One monograph is now in press. Since 1 January 1949 the Institution has issued 230 progress and technical reports on contract-sponsored research.

UNIVERSITY OF SOUTHERN CALIFORNIA

Work has continued on marine sediments in relation to origin of oil, and regeneration of nutrients from the bottom. This involves study of the change in composition of living plankton, organic débris, and sediments with investigations of the relationships between sediments and overlying waters.

SCHOOL OF FISHERIES, UNIVERSITY OF WASHINGTON (Prepared by RICHARD VAN CLEVE)

A short history of the School of Fisheries was presented to the last Pacific Science Congress and a discussion of the curriculum of the School appeared in the Progressive Fish Culturist (Vol. 14, No. 4, October, 1952). The general objectives of the School remain those of training fisheries biologists, primarily for research in conservation agencies and training technologists for work in the fishing industry. While specialized training must be given in order to provide an understanding of the problems which will be met, the principal emphasis during the entire training period, in both biology and technology, is on the basic background sciences that form the foundation for operations in these fields.

The School moved into its new building located on the shore of Portage Bay in November, 1950, and now has adequate space for classroom and laboratory instruction, as well as for student and faculty research. In addition, limited space is provided for other research agencies. Equipment includes that required for instruction and research in the field of freshwater biology, consisting of a 32-trough hatchery which also accommodates 14 tanks and 3 circular pools for rearing young trout and salmon. Five rectangular and 2 circular concrete pools are located within a wire enclosure on the lake side of the building. Running fresh water is pumped from Lake Union into an 18,000-gallon tank on top of the building to supply the hatchery and ponds. Supplementary emergency water can be diverted from the city water mains and can be de-chlorinated in two large activated-carbon filters. During the past two years the water supply from the lake has been unsuitable in summer because of high temperatures, and difficult to operate during winter because of the introduction of silt and mud through a poorly-constructed filter. As a result, a well was drilled on the campus and it is now supplying some 200 gallons per minute of practically ideal

water of almost constant temperature which rises no higher than 53°–54°F. in the summer and does not fall below 48° in the winter. This water is now being used in conjunction with the lake water. Two other laboratories for freshwater research are equipped with tanks and troughs. One is for the study of fish diseases, with its own sewage system; the other, with thermo-regulated mixers in the water supply, is for constant-temperature work. Facilities are also provided for field work in the freshwater area, with a carryall-truck and several small boats which may be used with an outboard motor for both class work and research in the nearby lakes.

Research in marine biology is carried out on our 50-foot converted Navy motor sailer provided with a double-drum trawling winch and a smaller accessory drum for handling lighter cable from which hydrographic instruments can be operated. In addition, outriggers have been installed for towing small plankton nets. The boat is used for operating various types of fishing gear in the Puget Sound area, and can also be used for dredges, etc. The study of live specimens in the laboratory is made possible by a self-contained saltwater aquarium which borrowed several features from similarly situated aquaria in Chicago and San Francisco. Salt water, passing from one of two storage tanks, moves through a series of Pyrex glass coils where it is cooled by refrigerated brine circulating around the coils. Water from the second tank is warmed while passing through a thermostatically controlled heating coil. The warm and cold water enter the aquarium room through separate pipes and provide a variety of temperatures when mixed in varying proportions. From the aquaria the water passes to the basement where it is filtered and pumped back to the reservoirs on the roof, completing the circuit. The saltwater system is operating successfully and is available for student instruction and research. With the completion of the system one experiment indicative of the type of research made possible is that of the acclimatization of salmon to salt water. This experiment is still in progress, and a number of silver and chinook salmon were raised for some months last season before they were suddenly struck with a bacterial disease introduced into the system from an unknown source. The disease has apparently been eliminated and another group of salmon are now being acclimated. This may provide an interesting research tool in the study of effects of various factors in the environment on the subsequent development of the salmon.

Facilities for instruction and research in technology include a well-equipped chemistry laboratory and a bacteriology laboratory, a small pilot plant containing all the basic machinery for canning, curing, and

processing fish and fish meal, and a small cold-storage plant with three rooms maintained at temperatures of 34°F., 0°F., and −40°F. respectively.

Research projects now in progress in freshwater fisheries biology include studies in such diverse fields as the nutrition of salmon and trout, the effects of temperature on the development of chinook salmon eggs and young, the detailed morphology of the sperm of salmonide, control of fungus in the eggs of rainbow trout, and the hybridization of cutthroat trout. In addition, a revision is being made in the nomenclature and imperfect description of western Nostostrican phylopods.

Research in Fisheries Technology is currently being re-organized following a change of personnel in that department. Present plans include an investigation into the thermal death times of bacteria and an investigation into a more convenient and efficient method of determining the degree and rate of spoilage in fish.

In marine fisheries biology, research into classification of fishes is carried on with the help of the fish collection of the School which at present contains over 600 genera, including fishes from Australia, New Zealand, the islands of both the North Pacific and South Pacific, both coasts of the United States, and Alaska and British Columbia. This collection is used for class instruction and research and is available for investigators from other institutions and agencies. Other studies in marine biology at present include a cooperative study, with the Washington State Department of Fisheries, of the population of a species of flatfish in a particular area of Puget Sound, which it is planned to extend as the different segments of the population are defined. Another study is that of the production and drift of eggs and young of fishes of the Sound. Other studies cover such features as the selective action of sampling gear and the ecology of various marine fishes. During the past year, contracts have been concluded between the University of Washington and the U.S. Army Corps of Engineers calling for the investigation of basic problems involved in the guiding of young snadronous fishes by electrical methods, and by non-electrical means such as light, sound, etc. Under these contracts which name the School of Fisheries as the agency responsible for the research, staffs have been assembled and we are now accumulating data in the prescribed areas.

Scholarships in the School of Fisheries are usually reserved for those students who have attended for at least a year and have thus established their ability as workers. However, support is available for students who are able to work, through activities of cooperating agen-

cies which sometimes have part-time work available throughout the academic year and full-time jobs in the summer. These jobs not only provide a means for students to support themselves but give valuable experience in the practical problems that will be met when they take on the work of management and research themselves. These cooperating agencies, which are located on or in the immediate vicinity of the campus include the following: The Applied Fisheries Laboratory, the Fisheries Research Institute, The International Fisheries Commission, The Washington State Department of Fisheries, The Washington State Game Department, and The U.S. Fish and Wildlife Service. One of the advantages to the School of Fisheries is that in addition to furnishing jobs for students, the staffs of these agencies form a valuable addition to the teaching staff of the School by providing lecturers and thorough supervision of research projects.

Training in the School of Fisheries is designed to fit students for their chosen field of fisheries biological research or technology, and is not intended to drill them in particular methods. Techniques in these fields are developing so rapidly that it would be useless to base a program entirely on the study of current methods. Basic principles of importance in developing new lines of research and new methods must be stressed in such a field.

Most students enter the School of Fisheries after two years of university training in the basic sciences of zoology, chemistry, and mathematics, with bacteriology and additional chemistry substituted for some zoology in the preliminary training of technologists. A course of lectures by leaders in fisheries research organizations is given during this preparatory period to aid students in orienting themselves in fisheries work. Background training in associated sciences is continued through the training.

The fisheries curriculum follows a logical sequence, beginning in the student's third year of university work with a year of comparative anatomy, physiology, and the classification and identification of fishes. In addition, a year's course is offered in the classification, life history, distribution, and methods of cultivation or capture of commercial aquatic invertebrates. These two courses furnish the foundation upon which all subsequent study is built. More advanced students are offered a year of the general biology of fishes, including the study of the migration and inter-relationships of fish populations; the reproduction, larval and postlarval life of marine fishes; and the relation of hydrographic conditions, food, etc., to the distribution, abundance, and availability of various species of fish. This is followed by a year's course in the

mathematical phases of fisheries biology, including the study of population growth and enumeration, population dynamics, and the influence of natural and artificial factors on variations in yield.

In the field of freshwater fisheries biology, a year's course is given covering methods of hatching, rearing, collection, and incubation of salmonides, and related problems; the nutrition of fishes; and finally, problems of management of freshwater fisheries. This is supplemented by a course in communicable diseases of fish as well as with a brief course in hydrological problems involved in the stream and lake environments.

As noted above, courses in fisheries technology have been added to the curriculum to meet the needs of the industry. At present a year's course is offered covering the application of chemistry, biology, and engineering to the canning, curing, and freezing of fish and shellfish, and to the preparation of fish by-products, oils, meals, etc. Another course extending through fall and winter quarters is comprised of lectures by authorities in various fields of the fishing industry. The latest machinery is being obtained for experimental work in technology —canning machinery has been loaned to the School of Fisheries by the American Can Company and the Anchor Glass Company. As equipment and facilities are added, further technological training of a more advanced character will be offered.

As the field of fisheries conservation develops, the need for a more profound understanding of the related sciences becomes more evident. Students must carry as much work as possible in chemistry, biology, and mathematics or related fields of physics, engineering and economics, according to their individual interests and abilities. A recent increase in the number of graduate students is therefore encouraging, since these men generally specialize even further in these related subjects. Future progress in all fields of fisheries will depend on a broader understanding of the basic sciences and the ability to apply this understanding to fisheries conservation and technology.

OCEANOGRAPHIC PROGRAM OF THE UNIVERSITY OF WASHINGTON: 1949-1953 (Prepared by RICHARD H. FLEMING)

The past four years have been characterized by many major developments in oceanography. Programs initiated after World War II have borne fruit, and many new research activities have been established and older ones reorganized. The latter is the situation at the University of Washington. Although the facilities described by Dr. T. G. Thompson at the last Congress (Thompson, 1952) remain essentially the same, the organization, program and staff have all been greatly

affected. These changes have been the result of reorganization within the University. In 1951 the Department of Oceanography was created in the College of Arts and Sciences and authorized to offer programs for both undergraduate and graduate students. A permanent, full-time faculty was therefore created. The facilities at Friday Harbor (that for some twenty years had, with the building on the main campus in Seattle, comprised the Oceanographic Laboratories) were established as an independent activity under the College of Arts and Sciences with the name of the Friday Harbor Laboratories. The other major development was that a research vessel, the 114-foot BROWN BEAR, was made available to the University through the Office of Naval Research of the Navy Department of Oceanography in surveys, research and training.

The educational program of the Department of Oceanography is unique in that undergraduates may elect oceanography as their major subject in studying for a Bachelor of Science degree. The nature of the courses offered in this program as well as in the graduate curricula will be described elsewhere at this Congress (Fleming, in press). The establishment of the Department carried with it the requirement for a regular full-time faculty. The composition of this faculty at the present time (November, 1953) is as follows:

Richard H. Fleming, Professor and Executive Officer of the Department
Thomas G. Thompson, Professor
Clifford A. Barnes, Associate Professor
Howard R. Gould, Assistant Professor
Maurice Rattray, Jr., Assistant Professor
Herbert F. Frolander, Instructor
Robert G. Paquette, Lecturer

In addition to the faculty there is a supporting staff of full-time research investigators, technicians, crew members, and student assistants totaling 45. This staff is largely supported by contract funds, principally derived from the Office of Naval Research. Chief research investigators on the staff are Dr. Richard G. Bader, Dr. Wayne V. Burt, and Dr. Robert G. Paquette.

Cooperative research with other departments of the University, that was characteristic of the earlier organization of the Oceanographic Laboratories, was gradually changed in nature. During the past year students working in the laboratories but studying toward degrees in Chemistry, Geology, Microbiology, etc., have completed their theses. Many of these are mentioned later in this paper.

The BROWN BEAR, belonging to the Fish and Wildlife Service, was made available to the University in the spring of 1951. The first year was largely spent in remodeling the vessel for oceanographic work. Although used intensively during the past eighteen months, certain installations still remain to be completed. The vessel is outfitted with all the conventional types of navigational and oceanographic gear, and perhaps her most unusual feature is the number of accommodations aboard. In order to provide for classes there are, in addition to cabins for the crew of eleven, cabins and bunks for a maximum of twenty-two in the scientific party. For short overnight cruises as many as thirty-five have been accommodated. Two major survey programs are being carried on. The first involves monthly cruises in the inland waters of the State of Washington, planned to provide comprehensive data for the interpretation of the seasonal cycles, the year-to-year variations, and to provide a basic understanding of the physical processes that maintain and control the general physical, chemical and biological conditions. The second program is directed toward an understanding of the currents, distribution of properties, and general oceanography of the oceanic waters. Some preliminary results of the second program are to be presented elsewhere at this Congress (Paquette and Barnes). The BROWN BEAR has also been employed on many special projects as well as for a floating classroom and laboratory for the students. When a smaller vessel is adequate, the Department uses the MV *Oncorhynchus,* a 55-foot research vessel maintained by the School of Fisheries, and during the summer the MV *Hydah* that is chartered for the use of the Friday Harbor Laboratories.

As is true of all the oceanographic activities in the United States, the large growth that has occurred since World War II is chiefly the result of the support provided by national and state agencies, in this case by the Office of Naval Research. Three such contract programs have been carried on. One is a general contract in support of basic oceanographic research; the second has covered the operations of the MV BROWN BEAR; and the third was a Literature Survey, financed by the Hydrographic Office, to bring together all available data and knowledge pertaining to the Puget Sound area. Additional support has been received from the Bonneville Power Administration for a detailed study of a transect of Puget Sound where it is planned to install a submarine power line. The size of the cable sheath, about 30 cm. the distance of about 6 km., and the fact that the cable must traverse steep slopes and a maximum depth of over 200 meters, raised innumerable engineering problems that required oceanographic information. The Department has devoted particular attention to the detailed microto-

pography in the section, the physical and mechanical properties of the sediments, the bottom population with special reference to forms that might attack the sheathing on the cable, and the currents to be encountered at various depths. During the past year, a grant was awarded by the National Science Foundation to support the work under Dr. T. G. Thompson or Dr. T. J. Chow on the study of copper and other heavy metals in the sea.

Because of the rapid development of the field programs during the past two years there has so far been little opportunity for the preparation and publication of formal papers. A large amount of materials has been prepared and is available in the form of reports upon request.

Before describing some of the research topics under investigation in the Department of Oceanography I wish to turn briefly to the Friday Harbor Laboratories, first because the activities of this institution have always been reported to the Pacific Science Congresses, and secondly because the Department of Oceanography continues to participate in its program. As mentioned earlier, the Laboratories are now a research facility in the College of Arts and Sciences. They are administered by an Executive Committee, Dr. Richard H. Fleming, director; and Dr. A. W. Martin, Jr., executive officer of the Department of Zoology, and Dr. C. Leo Hitchcock, executive officer of the Department of Botany, as members. The Laboratories function as an inter-departmental organization and during the past two summers, courses of instruction and research have been offered by the following departments: Botany, Fisheries, Geography, Meteorology, Oceanography, and Zoology. During the summer of 1953 there were in residence 43 students (almost entirely graduate students), 12 independent research investigators, and a faculty of 11. During the past four years, there have been notable improvements in the facilities. Ten housekeeping cottages have been built as well as five duplex buildings for family use, and five dormitories for single individuals. The housekeeping cottages, in particular, now make it possible for investigators to utilize the laboratories either on a continuous year-around basis or for short periods at any time of the year. The main improvement in the laboratory has been the installation of an all-glass sea water system that has made it possible to hatch the eggs and rear the larvae of many of the invertebrate animals. Dr. Emery Swan, who was appointed resident scientist in 1948, resigned in 1952 to accept a faculty position with the University of New Hampshire. No replacement has yet been made. Dr. Koji Hidaka was a visiting professor at the Laboratories during the summer of 1951.

Some of the major research activities of the Department of Oceanography will now be briefly outlined. Projects in chemical oceanography

are now supervised by Dr. Thompson, and until the reorganization, by Dr. Rex Robinson of the Department of Chemistry. Among the completed topics, and some still in progress:

(a) Development of an improved analytical method for the determination of potassium. (b) Development of a polarographic method for the determination of nitrate. (c) Examination of the factors affecting the determination of silicate ion in sea water. (d) Development and use of an accurate method for the determination of copper. The normal range of concentrations has been found to be between 0.014 and 0.050 microgram-atom per liter, with anomalous values in areas of stagnation. (e) Study of the physical–chemical processes involved in the freezing and thawing of sea water with particular reference to the types of salts precipitated and the partition of salts between the ice and the brine. (f) Development and application of methods for the evaluation of the various pigments in plankton. (g) Determination by means of flame spectrophotometry of the quantities of strontium in sea water. (h) Determination of titanium in sea water and marine organisms. (i) Development of a method for the determination of organic phosphorus.

Investigations in geological oceanography have been expanding, particularly those phases concerned with the project supported by the Bonneville Power Administration. A general reconnaissance of the sediments of Puget Sound has been the subject for a Ph.D. thesis of a student in the Department of Geology. Dr. Richard Bader, one of the research staff, has begun a study of the nature and amount of the organic detritus in marine sediments from a variety of local environments. Dr. Gould, who joined the faculty in the fall of 1953, plans to undertake a broad survey of the bathymetry and sediments of both the inshore and offshore areas.

It is in physical oceanography that the greatest amount of effort has been concentrated. As mentioned elsewhere (Paquette and Barnes) the offshore surveys of the BROWN BEAR have been directed toward two general problems, first, to learn what types of water movements are present and the nature of the permanent circulation, and second, to establish the nature of the processes affecting the outflow of the diluted waters of the Strait of Juan de Fuca and the Columbia River and their replacement at depth by saline ocean waters. In the inshore waters, the importance of the tides and tidal currents as factors in mixing and flushing have long been recognized. The other important variables are the amount and period of precipitation and runoff and the general climatic situation. In order to further evaluate these processes, detailed, systematic surveys are being conducted at monthly intervals.

Because of the complexity of these problems, a dynamic model of Puget Sound and Hood Canal was built in 1950. In this scale model the tides and tidal currents can be duplicated and studied in detail and in addition the effects of variable river discharge in salt water intrusion can be tested. Some of the results of these investigations are being reported elsewhere (Rattray, in press). Besides serving as a valuable research tool, the model is used as a teaching aid to demonstrate the nature of tides and tidal currents and also to develop in the students an understanding and appreciation of the local environment. The facilities are frequently used by fisheries investigators and pollution engineers to aid them in their studies. To supplement the model and to make available to both research investigators and students a means to study the nature and behavior of waves and tides under conditions much simpler than those in the Puget Sound Model, a tank with transparent sides 5 meters long and 2 meters wide and 0.5 meters deep has recently been completed.

Among the unique features available to the Department are Lakes Washington and Union that are connected to Puget Sound through a system of canals and locks. The penetration of salt water through the locks into Lake Union was in fact the topic that first turned the attention of Dr. Thompson to Oceanographic chemistry some 40 years ago. With increased use of the locks and limited supplies of fresh water runoff, during recent years there has been some penetration of salt into Lake Washington so that the average chlorinity has risen from about 3 p.p.m. to about 55 p.p.m. Although this increase may appear to be rather minor, the lake is large and it represents an intrusion of some 250,000 tons of sea salts. Mr. Gunter Seckel, under the direction of Dr. Rattray, has been investigating the physical processes involved in the mixing and movements of the fresh and salt water.

Under the leadership of Dr. C. A. Barnes, the Department has continued an active interest in Arctic oceanography. Faculty and staff members have participated each summer in surveys in the Arctic on board U.S. Naval Vessels.

Many of the programs in Marine Biology described in previous reports are being continued by the faculty of the Department of Zoology at the Friday Harbor Laboratories and in space made available to them in the Department of Oceanography. Projects carried on by faculty and staff of the Department of Oceanography have so far been relatively limited. In addition to the Bonneville Power Administration work, mentioned above, Dr. Frolander has begun a program of plankton sampling. During 1952–53 this was supplemented by the work of Dr.

John Barlow, who recently resigned to accept a faculty position with the Agricultural and Mechanical College of Texas.

Located as it is in a state with paramount interests in the sea, the Department of Oceanography continues to collaborate with, and provide consulting services for a large number of agencies concerned with fisheries, pollution control, coastal engineering, etc. Because of its proximity to the international boundary many of the problems under investigation are of mutual concern to the Canadian oceanographers under the leadership of Dr. John P. Tully and those at the Institute of Oceanography at the University of British Columbia. To foster an understanding of these problems and to profit from each other's experience, a series of informal meetings have been initiated.

The foregoing material indicates the ways in which the oceanographic activities of the University of Washington have increased and changed in emphasis during the past four years. It is felt that the creation of a Department of Oceanography with both undergraduate and graduate curricula is recognition that the study of the oceans has attained scientific maturity and that this field is of vital importance in the future development of the maritime nations.

The Pacific Science Association, since its organization in 1920, has always featured oceanography as one of its major fields of interest. Much credit is due to the Association and to the distinguished scientists who have inspired and led the Committee on Oceanography of the Pacific for the rapid development of the science of the sea in all countries bordering on our mighty ocean.

VIETNAM

Institutions

Les recherches océanographiques au Vietnam sont surtout celles de l'Institut Océanographique de Nhatrang. Un "Comité d'Océanographie et d'Études des Côtes" groupe, sous l'égide de la Marine Nationale Francaise, des physiciens, géologues, biologistes dont les travaux portent sur des questions marines; les titres de travaux effectues par ce comité sont cities al fin de la bibliographie.

L'Institut Océanographique de Nhatrang, que a rendu compte de ses travaux aux Ve, VIe et VIIe Pacific Science Congress a été, au ler Janvier 1952, transfere par le Gouvernement francais de l'Indochine au Vietnam devenu État independant. L'Indochine ayant disparu comme gouvernement, la France continue, par un accord avec le Vietnam, a apporter a l'Institut Océanographique de Nhatrang une assistance en finance et en personnel.

Cette modification institutionnelle, aussi bien que les troubles qui ont agité le territoire du Vietnam ont entrave la marche normale de l'Institution et ses travaux durant la période 1949–1953. C'est ainsi que trois scientifiques ont quitte l'Institution: Mr. Deroux, Chef laboratoire Coelentéres en 1950, Mr. Durand, Chef laboratoire d'Ichthyologie et Mr. Marche Marchad, Chef laboratoire Mollusques en 1951, et les travaux qu'lls poursuivaient ont été interrompus. Le personnel scientifique ne comporte en 1953 que Mr. Serene, Docteur es Sciences, Directeur, Chef de laboratoire des Crustaces et Mme. Fize, Licenciee es Sciences, Chef de laboratoire des Vertèbres marins et planctonologiste. Deux nouveaux chefs de laboratoires licencies es sciences prendront la charge de chef de laboratoire d'Océanographie physique et de chef de laboratoire d'Ecologie marine au ler Janvier 1954.

Divers chercheurs temporaires ont frequenté les laboratoires durant la période, en particulier en 1952 Mr. Waterman de l'Université de Yale, et en 1953 Mr. Dawson de l'Allan Hancock Foundation, Université de Californie, Messrs. Fontaine, Mercier, Saurin de l'Université d'Hanoi. Le laboratoire a procure des collections et du matériel d'études a divers chercheurs étrangers. Ces deux derniers aspects de l'activité du laboratoire seront développe en 1954 en liaison avec diverses institutions scientifiques de Vietnam et de France (Faculté des Sciences de l'Université d'Hanoi, Service des Pêches du Vietnam, Muséum National d'Histoire Naturelle de Paris, Office de la Recherche Scientifique d'Outre-Mer à Paris). Une assistance de l'UNESCO est envisagée dans ce sens. L'assistance appartée en 1952–53 par le Pacific Science Board (U.S.A.) sera sans doute continée. Lebut est de donner son plein emploi au laboratoire qui bien situe et bien equipe, manque de paronnel qualifie suffisant.

Instruction et Formation de Chercheurs Océanographes

L'Institut Océanographique de Nhatrang a formé des preparateurs specialises dans les divers secteurs de la faune marine; Poissons, Crustaces, Mollusques, Coelentéres; ces preparateurs assuant des charges correspondant a leur spécialité dans les laboratoires de l'Institut. Les étudiants en zoologie de la Faculté des Sciences d'Hanoi accomplissent chaque année un stage de 10 jours d'Initiation sur le terrain a la faune marine. Des fonctionnaires de Service des Pêches recoivent des éléments de formation scientifique et technique soit a l'Institut Océanographique de Nhatrang, soit dans divers centres internationaux de formation organises par le C.I.P.P. (FAO); en particulier en 1952 à Djakarta pour la Pisciculture et a Bangkok pour les statistiques des pêches, en 1953 a Bangkok pour la Pisciculture; en 1953–54 en scientifique recoit une

formation specialisée pour la pêche a l'Office Scientifique de la Recherche d'Outre-Mer à Paris.

Coopération Internationale

C'est au sein de Conseil Indo-Pacifique des Pêches et par les travaux de l'Institut Océanographique de Nhatrang que le Vietnam a participe surtout à la poursuite de programmes de recherches océanographiques dans le cadre d'une coopération internationale. Parmi ses contributions aux travaux de Nombreux comités de cet organisme, il faut signaler celle de Mr. Tran van Tri au sous-comité des Engins et celle de Mr. Serene au sous-comité d'Hydrologie.

On a vu plus haut que les laboratoires de l'Institut Océanographique de Nhatrang accueillent des chercheurs étrangers. Les echanges de Publications de la bibliothèque et les relations de travail des laboratoires de faunistique de l'Institut Océanographique de Nhatrang ont intéressé pendant la période environ 500 correspondants étrangers.

Travaux

La poursuite des travaux de l'Institut Océanographique de Nhatrang durant la période 1949–53 a été handicapée par la situation exposée plus haut. C'est ainse qu'en Océanographie physique aucune recherche méritant d'etre mentionée n'a été accomplie. De même les recherches planctoniques ont été interrompues. Ces deux laboratoires fonctionneront a nouveau en 1954.

Inventaire et Museum de la Faune Marine

Dans une publication (1952) donnant un bilant de nos connaissances sur la faune marine benthique des invertèbres de l'Indochine, Mr. Dawydoff cite 59 espèces de Foraminifères, 157 de Porifères, 72 d'Hydrozoaires, 70 d'Alcyonnides, Helioporidae, Xoenidae, 29 de Pennatulides, 50 de Gorgonides, 172 d'Hexacorallides, 250 de Polychètes (Plus de 10,000 spécimens), 20 de Vermidiens Echuiens, 40 de Siponculiens, 70 de Bryozoaires; 800 espèces de Mollusques gastéropodes et lamellibranches, 85 de Nudibranches, 13 d'Amphineures, 11 de Cephalopodes; 63 espèces d'Holothuries, 40 d'Astérides, 50 d'Ophiures, 60 d'Echinides et 50 de Crinoides; 65 de Crustacées Cirripedes, 47 de Cumacées, 24 d'Isopodes, 23 d'Amphipodes, 35 espèces de Decapodes anomoures et 50 de Macroures, 300 de Brachyoures, 37 de Stomatopodes; 40 espèces de Chordes. L'ensemble couvre environ 3,000 espèces. Les collections correspondant à cet inventaire ont malheureusement été dispersées entre les differents specialistes qui en ont assure l'étude. Elles comprenaient plus de 50 espèces nouvelles; par exemple 10 nouvelles

espèces de Cténophores, 15 espèces nouvelles et 3 genres nouveaux d'Holothuries.

D'Institut Océanographique de Nhatrang a depuis 1949 constitue à Nhatrang un Muséum de la Faune marine du Vietnam dont les collections n'intéressant encore que les Poissons, les Crustacées, les Mollusques et les Coraux, ont enregistres, de 1949 à 1953, 30,000 echantillons, correspondant à environ 3,000 espèces determinées. Le catalogue de ce Muséum constitue un nouvel inventaire faunistique, qui celue-ci porte références aux specimens des collections du Musée de Nhatrang. Sur les 3,000 espèces de ce catalogue, il y a environ 1,000 espèces de poissons, les autres étant des invertèbres.

L'étude des collections pour l'établissement de ce catalogue de déjà permis la mise au point de diverses questions de faunistique, qui ont fait l'Object de publication, spécialement sur les Stomatopodes et les Brachyures.

La flore algologique de la Baie de Nhatrang a été établi par le Professeur Dawson, qui presente une communication sur le sujet au présent Congrès.

Au point de développement ou se trouve actuellement les recherches d'Océanographie biologique au Vietnam, l'établissement préalable d'un tel musée de référence faunistique était indispensable avant d'entreprendre toutes recherches de Biologie; cellesci sont actuellement amorcées, spécialement en liaison avec le Bureau d'études des pêches et portent sur les principales espèces de poissons a interet economique; le laboratoire de planctonologie et d'Océanographie physique repredront leur activité en 1954 en relation avec ces recherches.

Études de Peches

La creation en 1952 d'un Service des pêches du Vietnam a conduit a preciser le rôle du Bureau d'études des pêches de l'Institut Océanographique de Nhatrang comme organe de liaison entre les recherches scientifiques et techniques des laboratoires et les recherches d'application pratiques du ressort du Service des pêches.

Ce bureau forme du personnel technique pour le Service des pêches et étudie a les principales espèces de poissons et produits de la mer a interet economique alimentaire: Taxonomie vernaculaire, biologie, migrations, etc. . . . (la technologie des engins et methodes de pêches), la technologie de la preparation des produits alimentaires d'origine marine.

Pour tout cela, il procéde a des enquetes et tient a jour une documentation sur l'état de ces questions, principalement dans les pays de la zone indo-pacifique. Par depouillement des publication, il a éta-

bli par exemple un fichier iconographique et descriptif des engins de pêche de la region indo-pacifique (2,500 engins fiches).

S'appuyant sur cette documentation, il diffuse des documents sur les questions de pêche du Vietnam et publie des études sur les techniques de pêche es Vietnamiens. Son programme d'activité est établi en liaison avec les travaux du Conseil Indo-Pacifique des Pêches.

November 17, 1953—2:30 P.M.

DIVISIONAL DISCUSSIONS: PROBLEMS IN THE DEVELOPMENT OF METEOROLOGY AND OCEANOGRAPHY IN THE PACIFIC

Convener: Dr. Thomas G. Thompson, University of Washington, Seattle 5, Washington, U.S.A.

Secretary: Mr. Ricardo G. Lao, Bureau of Fisheries, Manila.

This meeting was held jointly with the Division of Meteorology. Discussed in the meeting were the problems in the development of Meteorology and Oceanography in the Pacific.

November 18, 1953

SYMPOSIUM ON EXPLOITATION AND UTILIZATION OF PRODUCTS FROM THE SEA

Convener: Dr. W. A. Clemens, Institute of Oceanography, University of British Columbia, Vancouver, Canada.

Secretary: Mr. Nazario A. Pidlaoan, Bureau of Fisheries, Manila.

PROCEEDINGS

The symposium started at 8:55 a.m. Dr. Clemens made the opening remarks by saying that he was greatly honored to be the chairman and wished to acknowledge the great assistance given him by Dr. D. V. Villadolid, Director of Fisheries in the Philippines. He pointed out that this is the region of the sea which has always been exploited but stated that certain areas are still underexploited with respect to certain species of fish. He mentioned that the tunas could support a major fishery in the high seas, and since the papers presented in the symposium cover a wide range, he is certain that a vivid picture of conditions existing in various parts of the Indo-Pacific region could be obtained. But on account of the limited time not all the papers could be presented in full. He stated that a committee composed of Dr. Hiyama, Dr. Miller, Mr. Pidlaoan and himself had determined those papers in which the author would be given 10 minutes for reading and 5 minutes for discussion; papers in which the abstract should be read, and papers which would be read only by the title. The committee had also agreed to arrange the program in an order a little different from that of the original program for the purpose of putting together papers relating to the same subject. For example, papers related to tunas were put together; papers related to the open sea were put together, and then papers in shore work resources were put together.

The order of the presentation of papers was as follows:

I. Biological Oceanography. W. A. Clemens, Institutes of Oceanography and Fisheries, University of British Columbia, Vancouver, Canada.

The author after reading his paper said that we are far behind European workers in knowing and recognizing the organisms that live in our waters. So we have a great deal of descriptive work to do along taxonomic lines.

Dr. R. W. Hiatt said that the flora and fauna in the Pacific is exceedingly large that the life time of a generation would probably not be enough to study them taxonomically. He suggested that the important plants and animals which characterized the different types of zonation be recognized first rather than be lost in the bulk of animals present in a particular region.

2. A New Approach to the Study of Marine Resources—the California Cooperative Oceanic Fisheries Investigations. Robert C. Miller, California Academy of Sciences, San Francisco, California, U.S.A.
3. Nourishment of Central Pacific Stocks of Tuna by the Equatorial Circulation System. Oscar E. Sette, Pacific Oceanic Fishery Investigations, Fish and Wildlife Service, Honolulu, Hawaii.
4. Development and Conservation of the Tuna Fisheries of the Pacific. Milner B. Schaefer, Inter-American Tropical Tuna Commission.
   (Abstract read by Dr. W. A. Clemens)
5. Recent Studies on Tunas and Marlins in Japan. Hiroshi Nakamura and Yoshio Hiyama, Nankai Regional Fisheries Research Laboratory, Kochi, Japan, and Fisheries Institute, Faculty of Agriculture, Tokyo University, Japan, respectively.
6. Are the World-wide Declines in Sardine Catches Related? John C. Marr and James E. Böhlke, South Pacific Fishery Investigations, U.S. Fish and Wildlife Service, 450-B Jordan Hall, Stanford, California, U.S.A.
   (Title)
7. The Products of the Sea and Their Exploitation and Utilization in Pakistan. M. R. Khan, Central Fisheries Department, Government of Pakistan, Karachi, Pakistan.
8. Some Factors Bearing on the Utilization of Marine Products of the West Coast of Canada. Neal M. Carter, Pacific Fisheries Experimental Station, Fisheries Research Board of Canada, Vancouver, B. C., Canada.
   (Abstract read by Dr. W. A. Clemens)
9. Fabrication, Definition et Reglementation de la Sauce de Poisson Vietnamienne "Nuoc-mam", J. Guillerm and A. Vialard-Godou, Laboratoire du Nuoc-mam à l'Institut Pasteur de Saigon, Vietnam.
   (Title)
10. Studies on Agar-agar in Japan. T. Yanagawa and K. Tanii, Doshisha University, Kyoto, Japan, and Northeast Sea Regional Fisheries Research Institute, Shiogama City, Japan, respectively.
   (Title)

11. A Report on the Studies Made in Japan on Pearl Culture. Yoshiichi Matsui, Nippon Institute for Scientific Research on Pearls, Kyoto, Japan.

(Presented by Dr. Okada)

12. Fundamental Studies on the Fish Lamp. N. Y. Kawamoto, Faculty of Fisheries, Prefectural University of Mie, Tsu, Mie Prefecture, Japan.

(Presented by Dr. Y. Hiyama)

13. Coaction in Lamp-Communities. Hiroshi Maeda, Shimonoseki College of Fisheries, Yamaguchi Prefecture, Japan.

(Presented by Dr. Y. Hiyama)

There was a lively discussion on this subject. Some one in the crowd raised a question in the use of the word synecological. But since the author of the paper was not present, no one was able to answer the question.

By this time it was 12:00 o'clock. The session was adjourned, to resume at 2:00 o'clock in the afternoon.

The afternoon session was started with the six papers from Chile. Since none of the authors were present, they were read by the title and Dr. Milton W. Lobell was requested by the chairman to speak briefly on the fisheries of Chile. The important points brought out by Dr. Lobell were as follows:

A considerable amount of work has been done on the movement of waters in the coast of Chile and a great deal has yet to be done. From these studies, it appeared that the great productivity of the water is due to certain periodic upwelling in certain specific areas. The fisheries in Chile are imminently tied with certain oceanographic factors. The warm oceanic waters along the coast in a number of towns in Peru for instance accounts for the existence of tunas, sword fish and other similar tropical fishes in these places.

The anchovies are found in great abundance in the Northern coast of Chile. They constitute the favorite food of the guano birds, so there is at the present time some controversy whether this be allowed to continue or whether the fishermen should be allowed to fish the anchovies and convert them directly to fish meal.

The southern part of Chile is very rich in mollusc and crustacean. An interesting thing to note is the striking parallelism between the fishes found in the northern and southern Pacific areas. There is, for instance, a type of sardine in Chile which is taxonomically quite similar to the California sardine.

The fisheries in Chile have been increasing quite rapidly. Chile has to increase the phases of her export market rather than domestic

consumption because the population of the country is very small. The fishery product is based to a large extent on the hake production. Filleting of fish was started quite recently. This product finds a tremendous market in public institutions, which are required by law to sell fish at least twice a week.

Chile has always been interested in the development of her fishery resources and the good number of men coming up will surely make significant contribution to the knowledge of her oceanography and fisheries biology.

14. The Hake Fisheries off the West Coast of Chile. Erik M. Poulsen, International Commission for the Northwest Atlantic Fisheries, St. Andrews, N. B., Canada.

(Title)

15. Report on the Algae of the Chilean Seas. Hector Etcheverry-Daza, Botany Section, Marine Biological Station, University of Chile, Montemar, Chile.

(Title)

16. The Fisheries of Chile. B.F. Osorio-Tafall, Oficina Regional para Sudamerica Occidental, Santiago de Chile, Chile.

(Title)

17. Preliminary List of Chilean Fishes and their Vernacular Names. Fernando de Buen, FAO Fisheries Expert, Technical Assistance Program, Chile.

(Title)

18. Edible Shellfish of the Chilean Coast. Francisco Riveros-Zuñiga, Estacion de Biologica Marina de la Universidad de Chile.

(Title)

19. Notes on the Commercially Important Fishes of Chile. Parmenio A. Yañez, University of Chile, Marine Biological Station, Montemar, Chile.

(Title)

20. Oceanographical and Fisheries Research in India. N. Kesava Panikkar, Central Marine Fisheries Research Station, Mandapam, S. India.

(Presented by Dr. N. K. Panikkar)

21. Oceanography and Fisheries. G. L. Kesteven, Marine Fisheries Section, Food and Agriculture Organization, Rome, Italy.

(Presented by Dr. C. Miles)

22. Factors in the Utilization of Canada's Pacific Marine Resources. J. L. Hart, Pacific Biological Station, Nanaimo, B. C., Canada.

(Abstract read by Dr. W. A. Clemens)

23. Poisonous Fishes and their Relationship to Marine Food Resources in the Pacific Area. Bruce W. Halstead, School of Tropical and Preventive Medicine, College of Medical Evangelists, Loma Linda, California, U.S.A.

This paper was presented with great enthusiasm. It seemed everyone wanted to say something on the subject. Mr. Domantay told the audience that the Moros remove certain organs of the poisonous fish and ate the rest. Mr. Martin and Mr. Umali spoke on the poisonous fishes in the Philippines.

The author has signified his eagerness to communicate with anyone interested in poisonous fishes.

24. Simple and Rapid Colorimetric Method for the Estimation of Ammonia in Fish Meat. Uyuo Ota, Faculty of Fisheries, Kagoshima University, Japan.

(Title)

25. A New Method for Investigating Fish Meat Putrefaction. Kiichi Murata and Keiichi Ohoishi, Hokkaido University, Japan.

(Title)

26. Recent Trend of Research on the Freshness of Fish Meat in Japan. Koishi Amano, Tokai Regional Fisheries Research Laboratory, Tokyo, Japan.

(Title)

The symposium lasted up to 4:10 p.m.

27. Some Aspects of Fisheries Problems in the South Pacific Area. A. H. J. Kroon, Economic Development, South Pacific Commission, Noumea, New Caledonia.

(Paper submitted after the Congress sessions.)

BIOLOGICAL OCEANOGRAPHY

By W. A. Clemens
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The study of the ocean is usually referred to as oceanography. Various sciences are involved such as physics, chemistry, biology, geology, meteorology,—in other words, oceanography is not a single science but the application of many sciences in the study of the ocean. The phases have been designated as physical oceanography, chemical oceanography, and so on.

I have been trying to visualize the place of biological oceanography within the general compass of oceanography. In doing so I have had in mind the fact that the "Challenger" expedition is usually referred to as the beginning of the science of oceanography and, as Merriman (1949) has pointed out, this expedition was primarily a biological one having for its objective the exploration of life in the depths of the sea. Fortunately men interested in the physics and chemistry of the ocean were included in the project and so there was laid the foundation for the co-operation of representatives of the various sciences in the study of the sea.

I am inclined to suggest that there are possibly four phases of biological oceanography. The first has to do with the contribution of biological processes to the physical and chemical conditions in the ocean, that is, the relations of living organisms to the oxygen, carbon dioxide, phosphate, nitrate, silicate and other chemical states and processes; to light penetration, sound transmission, bottom deposits, coral reef building, etc. For these aspects, terms might be used, such as: bio-oceano-chemistry and bio-oceano-physics.

A second phase involves the use of organisms, planktonic or other, for the identification of water masses including the movements of these. I recall for example the paper by Kemp (1938), in which he tells the story of how the water masses entering the English Channel may be identified by the species of *Sagitta* present. Certain species of fishes may be used as indicators.

A third phase and the one which has received most attention is the study of ocean conditions as an environment for populations of living organisms. It is this aspect of biological oceanography which

resembles marine biology or ecology. The difference between the two is in viewpoint or outlook. In biological oceanography, the investigator thinks in terms of the ocean and how the conditions throughout their ranges and cycles are related to the production, behaviour, distribution, etc. of the plant and animal populations. On the other hand in marine ecology, the investigator thinks in terms of the organisms and their responses to factors in the environment. There does appear to be a definite difference in approach, although the end results may be essentially similar in some instances. However, I think it important to emphasize the fact that the biological oceanographer should be, not merely a biologist, but an oceanographer in the broadest sense with a thorough understanding of the physico-chemical and dynamic conditions in the ocean.

A fourth phase has to do with the interrelations between the physico-chemical conditions and the biological productivity of the ocean. In this all plants and animals are involved and the final objective is a comprehension of total productivity. Most frequently attempts are made to correlate the physico-chemical conditions with the quantities of plants and animals at specific times and places. These particular studies have to do with standing crops or biomass. Much attention has been centred on phytoplankton as the basic element in the complex food chains. In the investigation of plankton, there are two phases to be considered. One is the broad survey or synoptic type which should accompany and parallel the physico-chemical. The physico-chemical oceanographer gathers many data on the distribution of temperatures, salinities, oxygen, etc., and develops broad pictures of states and circulation systems. The biological oceanographer needs to proceed to obtain his data in a parallel manner. He needs to develop a plankton sampler which will operate with much the same facility as the water bottle and the bathythermograph and develop methods for processing the collections by standard procedures which permit as speedy analyses as in the case of the physico-chemical data. The other phase of plankton study relates to detailed specific problems within limited areas. Here the physico-chemical and biological procedures may be modified, elaborated and otherwise developed as the specific problems may require. The time element may be less important than it is where a series of stations is being occupied over a wide geographical range.

On the basis of the above remarks, I shall attempt to present a brief statement concerning a few problems in biological oceanography occurring on the Pacific coast of Canada.

In the field of bio-oceano-chemistry there is a problem concerning the origin and abundance of phosphate in Georgia Strait. Lucas and

Hutchinson (1927), Hutchinson (1928), Hutchinson, Lucas and McPhail (1929), and Lucas (1929), stated that the contribution from rivers, especially the Fraser River, was considerable and that this phosphate tended to be stored or "conserved" thus forming a reservoir of phosphate. The water of Juan de Fuca Strait, which enters Georgia Strait in the tidal flows, is relatively high in phosphate and may also be a factor in maintaining the high values. Throughout the seasons and from one location to another the amount of phosphate may vary according to the "blooming" of the phyto-plankton and the disintegration of both phyto- and zoo-plankton. A detailed study of the phosphate cycle in this body of water, including the interchange between the water and the bottom sediments, with their contained living organisms, would contribute much to an understanding of a series of fundamental processes.

The current system off the west coast of Vancouver Island is being steadily elucidated by Tully (1942) and associates. In brief, the freshwater from the Fraser River and from the various inlets moves northwest along the coast. The water of this current is of slightly reduced salinity and low temperature. Beyond the margin of the continental shelf, some hundred miles offshore, the California current flows southeastward. This water is of high salinity and, during the summer, of relatively high temperature. Between these two currents is a region of complex eddies with mixing of the two above-mentioned water masses. In addition, upwelling occurs during certain portions of the year. Knowledge of the character of the plankton organisms in these areas is very limited. It would seem that a plankton investigation coincident with the physico-chemical program might provide useful information in regard to plankton organisms as indicators of the two water masses and of the nature and extent of mixing. It is possible also that the distribution of plankton organisms in inlets may be used to confirm some of the complicated circulation features as determined by physical dynamic studies.

As a result of oceanographic studies by many investigators, the physical and chemical characteristics of the waters of Georgia and Juan de Fuca Straits as well as the dynamics of these waters, with their complicated features by reason of the outflow of the Fraser River and the strong tidal flows, are well known. On the other hand the fishery biologists have accumulated a very great deal of information concerning the life history of the Pacific herring. In late spring and early summer very large numbers of young herring go out from Georgia Strait to the region off the entrance to Juan de Fuca Strait and to some extent northwestward off Barkley Sound. There they feed and grow and eventually, as three-year-old fish for the most part, enter Juan de Fuca

Strait in late summer and early fall, appear in large schools among the various channels off the east coast of Vancouver Island, and spawn in March. This cycle of events in the life history of the herring is essentially similar to that of the sockeye salmon, and I suggest that the basic factors are similar to those which I have postulated for the salmon (Clemens 1951). I am confident that a careful investigation will reveal an intimate relationship between the annual cycle of the environment and the physiological cycle of the fish.

It has been well-established that the California current divides off the British Columbia coast with a portion turning northwestward to form the Alaskan gyro while the main current proceeds southeastward. It is suspected that considerable variations occur throughout the years in the division point of the current. It is possible that such vagaries of the water masses may be related to the variations in the distribution of the albacore and in the migrations of Pacific salmon.

Finally in the field of biological productivity no attack has been made on the problem since the work of Hutchinson, Lucas and associates in 1927 to 1929, when they investigated the relation of the physical and chemical properties of the water of Georgia Strait to the quantities of phytoplankton occurring during the summer months. The coastal waters of British Columbia with all their complicated features by reason of heavy river discharge, strong tidal currents and channel turbulence, offer a challenging field of fundamental research in biological productivity.

The examples may serve to illustrate a few of the exciting problems existing for the biological oceanographer on the Pacific coast of Canada.

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A NEW APPROACH TO THE STUDY OF MARINE RESOURCES —THE CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

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The importance of integrating oceanographic and fisheries research is too obvious to require restatement. Such integration has been achieved in specific areas, especially in the North Sea and perhaps rather generally in the North Atlantic. In the Pacific Ocean, which occupies well over one-third of the globe and is so vast that even its preliminary exploration has not been completed, such integration has rarely been achieved. To this statement there are a few notable exceptions, among them the Philippine Fishery Program and the POFI operations base on Hawaii.

When the California sardine fishery, which used to be one of the great fisheries of the world, began a sudden and disastrous decline from an approximate six hundred thousand tons a year to a point where the fishery is practically non-existent, fisheries biologists discovered that they had no backlog of oceanographic information to explain this phenomenal decline, nor to predict the future of the fishery.

In 1947 the State of California embarked on a remarkable experiment in scientific research. Legislation was adopted establishing a Marine Research Committee of nine members, representing the Fish and Game Commission, the fishing industry, and the public. Under the sponsorship of this Committee five agencies have been asked to cooperate in solving the sardine problem—the California Academy of Sciences, the California Department of Fish and Game, the Hopkins Marine Station of Stanford University, the Scripps Institution of Oceanography of the University of California, and the U.S. Fish and Wildlife Service. The research program is laid out and coordinated by a Technical Advisory Committee made up of representatives of these operating agencies.

It is significant that the legislation under which the Marine Research Committee was established was sponsored by the fishing industry itself, and that the industry requested the Legislature to increase the landing tax on sardines by an amount of fifty cents a ton, the revenue from this tax to be used specifically for research on the sardine. Sub-

sequently when the income from this tax proved inadequate, the Legislature, again at the request of the fishing industry, increased the special tax to a dollar a ton, and extended it to landings of anchovy, jack mackerel, Pacific mackerel, and squid. This may well be the first time in history that an industry has requested an increase in its own taxes to finance research, and the attitude that prompted it represents an encouraging trend away from the concept of reckless exploitation toward that of scientific management and conservation.

The reasons for developing a cooperative program involving several agencies were the magnitude of the undertaking and the desire to utilize as effectively as possible the available scientific manpower, experience, and research facilities. Some idea of the immensity of the project can be gained from the fact that hydrographic stations have been occupied, many of them on a monthly schedule, over an area of 670,000 square miles.

Each cooperating agency has accepted responsibility for one or more specific phases of the investigation:

(1) The California Academy of Sciences is working on the behavior and physiology of sardines as these can be studied under aquarium conditions.

(2) The California Division of Fish and Game is concentrating on statistical studies of year classes, on young fish surveys, and on methods of locating and identifying sardine schools.

(3) The Hopkins Marine Station of Stanford University is studying temperature patterns and changes throughout the year, in and near Monterey Bay.

(4) The Scripps Institution of Oceanography of the University of California is conducting extensive oceanographic surveys, (including plankton studies), and processing all the physical and chemical oceanographic data obtained by any of the cooperating agencies.

(5) The U.S. Fish and Wildlife Service is responsible primarily for spawning surveys, and is also conducting some more general phases of the investigation.

This division of work is not rigid and inflexible; often personnel from two or more agencies work on projects together.

Although the investigation is still far from completion, the following conclusions may be drawn:

(1) The decline of the fishery was due to a combination of intense fishing effort and a succession of poor spawning years. Even though overfishing may not be the primary cause of the decline, when a fishery declines for any reason, overfishing then inevitably occurs, because greater fishing effort is concentrated on a smaller population. Thus

a vicious circle is established which, unless the fishery is regulated, will continue until the catch becomes so small that it is unprofitable to fish.

(2) Spawning of sardines occurs in two principal areas, one off Southern and one off central Baja California. Spawning in the former of these areas has been poor in recent years, and it is not definitely known whether sardines spawned off central Baja California contribute significantly to the California fishery.

(3) Spawning is limited to a rather narrow temperature range (of the order of 12.5°C. to 16.5°C.), so that changes in the temperature of the water from year to year may result in poor spawning or a shift of the spawning areas.

(4) The amount of upwelling of nutrient-rich water from the ocean depths appears to be an important factor in providing food for young and mature sardines, and perhaps affects spawning by its influence on surface temperatures. Along the California coast, upwelling varies from year to year, especially with the velocity of the prevailing northwest winds. These winds also, by their effect on the velocity of the California current and the inshore counter current, may directly affect the movement and the availability of sardines at a given time and place.

A further general observation may be made. The decline in the sardine fishery has resulted in a diversification of fishing effort, which is, in the long range view, desirable. As shown in Figure 1, there has been a rather rapid increase in the take of other fishes since the sardine fishery began its rapid and catastrophic decline. Obviously not all of this increase has been due to the lack of sardines, but certainly some of it has been due to the fact that sardine fishermen have been forced into other lines of fishing endeavour.

It is now necessary to conduct studies on other fishes (some of which are referred to as "substitute sardines") to insure that they do not suffer a similar fate to the sardine. The research program, known as the California Cooperative Oceanic Fisheries Investigations, is being expanded to include anchovy, Pacific mackerel and jack mackerel. Other species are also given attention as they come to notice incidentally in the course of the work.

It is believed that the oceanographic information being obtained in these investigations will be of importance in the solution of many other fisheries problems in the future. It is believed also that this type of cooperative undertaking, in which a number of institutions offer their facilities and trained personnel toward the solution of a major fisheries problem, provides an effective method of advancing our knowledge of the science of the sea.

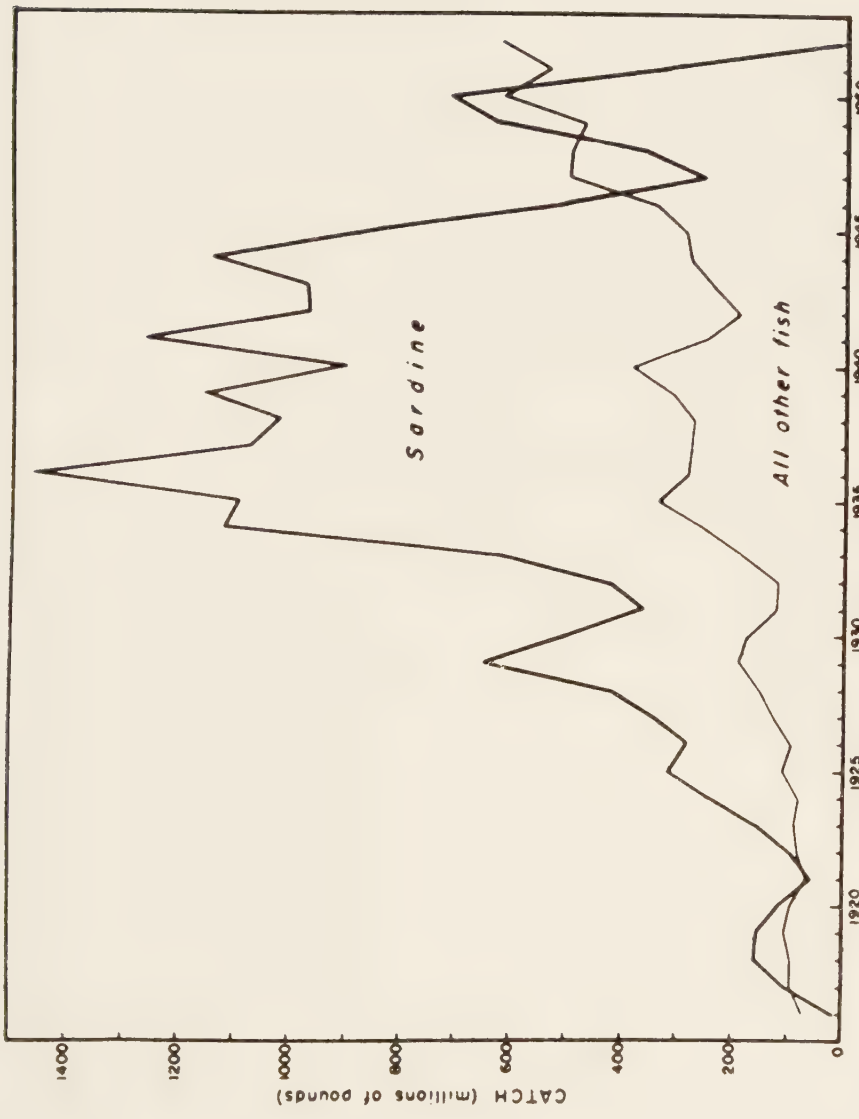

FIG. 1.—Landings of California sardines from 1916 to 1952 compared with landings of all other fish in California (Courtesy of California State Marine Research Committee).

NOURISHMENT OF CENTRAL PACIFIC STOCKS OF TUNA BY THE EQUATORIAL CIRCULATION SYSTEM

By Oscar E. Sette
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An extensive program pursued by the Fish and Wildlife Service from its Honolulu laboratory for Pacific Oceanic Fishery Investigations has been directed toward discovery of high-seas fishery resources through study of oceanic productivity. This program, uniting oceanography, biology, and fishery investigation probably has amassed more information regarding the physical and chemical properties of the upper-level waters, the structure of the upper-level current system, the abundance and distribution of plankton, and the occurrence of harvestable fish in the low latitudes of the east-central Pacific than has been available previously for any mid-ocean area anywhere.

Up to March 1953 we have occupied 390 hydrographic stations forming 22 sections transverse to the equatorial current system at various longitudes from 140°W. to the 180th meridian (Fig. 1). Most of these have been accompanied by quantitative zooplankton hauls and additional plankton hauls have been made on fishing voyages, making a total of 399. There have been 218 fishing stations, forming 20 transects of the equatorial zone (Fig. 2), as well as several additional patterns of fishing survey over special areas. Hydrographic and fishing trips have provided 4,442 bathythermograms. Reports have been published, are in preparation, or are planned to cover various aspects at various stages of our progress. At this time, it is possible to give a broad preliminary outline of the results as they are now emerging.

The dominant energy source for equatorial ocean circulation is the trade wind system. In the oceanic portion of the eastern half of the equatorial Pacific, where there is practically no emergent land to impose topographical modifications, the direction and force of the wind govern rather completely the details of the equatorial current system. As a consequence of the circulation there results a chain of biological events that culminate in an abundant stock of equatorial yellowfin tuna, *Neothunnus macropterus*, Temminck and Schlegel. We shall examine first in cross-section and then in plan view this oceanic equatorial production system.

In a paper now in press Cromwell[1] has erected a hypothetical model which postulates the effect of winds from various directions on the ocean circulation and which is consistent with the empirically determined hydrographical and biological conditions. He has kindly permitted our use here of Figure 3 (Fig. 6 of his paper) and has prepared the following statement on the particular effects of wind which are most significant to the present discussion.

"Figure 3 shows directions of current transport (solid arrows) that would exist near the equator under various wind conditions were there no pressure gradient force acting.[2] For each wind direction the meridional components of current transport (dotted arrows) are drawn to emphasize the regions of divergence (Div.) and convergence (Conv.). The magnitude of the current is drawn everywhere constant, and hence the regions of divergence and convergence shown are associated with differences in current direction only. Upwelling can occur in the regions of horizontal divergence.

"The intensity of the horizontal divergence is partially dependent on the current magnitude which increases with increasing wind speed. Thus, during strong trade winds near the equator, horizontal divergence and upwelling will be intense and the sea surface temperature will be low.

"Figure 3 shows further that the position of the convergent and divergent currents depend on the wind direction. During a steady east wind horizontal divergence is centered at the equator. When the wind is southeast there is horizontal convergence in the northern part of the equatorial region between the 3° parallels, with the divergent current now centered somewhat south of the equator."

As an empirical example for examining the distribution of properties in the meridional plane, for inferring the circulation, and for seeing the effect of the circulation on plankton and tuna distribution, we shall use Cruise 11 of the Fish and Wildlife Service vessel HUGH M. SMITH (Fig. 4) which occupied the period August 20 to October 6, 1951. On this cruise the SMITH proceeded southward along meridian 150° W. occupying fishing stations, and returned northward along the same meridian occupying hydrographic stations (Fig. 5). Bathythermograms and zooplankton hauls were taken on both transits. The south-

[1] Cromwell, Townsend: "Circulation in a meridional plane in the central equatorial Pacific." In Press. *Journal of Marine Research.*

[2] In Figure 3 the vectors at the 3° parallels are in accordance with Ekman's theory of the pure wind drift current (Ekman 1905), i.e., the current transport is indicated at one right angle *cum sole* with the generating wind. Ekman's theory is considered to apply 3° from the equator in accordance with a recent paper by Weenink and Groen (on the computation of surface current velocities in the equatorial regions from wind data. *Proc. of Koninkl. Nederl. Akad. van Wetenschappen,* Amsterdam, Ser. B, 55, No. 3, pp. 239-246, 1952) in which they conclude that at ". . . 2 or 3 degrees . . ." and higher latitudes the internal frictional force is small compared to the Coriolis force. Cromwell has discussed completely the assumptions involved in constructing the figure.

bound transit was interrupted for 15 days at 2°N. latitude to occupy an east-west line of fishing stations. These will be omitted from our discussion.[3] The observations on temperature, phosphate, plankton, and tuna are diagramed in Figures 6 and 7.

The upwelling at or very near the equator is evident at the surface from the drop in temperature, and in cross section by the extension to the surface of the water cooler than 26.7°C (80°F) and richer in phosphate than 0.4 microgram atoms per liter. The transport near the surface of the upwelled water northward and southward from the equator is evident from the extension of the higher phosphate concentration in both directions from the equator. It is also evidenced by the northward component in the direction of longline drift [4] north of the equator and the southward component when they were fished south of the equator (Fig. 6B).

The movement of the water in surface layers toward the north away from the equator decelerates and may terminate. In either event there is convergence and probably sinking. The northern limit of the convergent zone was at 4°50′N. latitude at the time of the northbound passage of the SMITH and is clearly marked by the abrupt change in surface temperature at that latitude (Fig. 7A). This also approximates the southern boundary of the countercurrent. A month earlier, during the southbound passage, this feature was about one degree farther south judging from the change in slope of the 15.6° and 26.7°C isotherms and from the drift of the longline gear (Figs. 6A and B).

Yellowfin tuna were markedly concentrated between the equator and the northern limit of the convergence, the catch averaging four times as many fish per unit of fishing effort between 1° and 6°N. as elsewhere (Fig. 6D).

In the sequence of events between the enrichment of the water at the equator and the production of food for the tuna, several trophic levels intervene. According to stomach examinations tuna eat practically all but the largest members of the bathypelagic nekton, small fish and squid forming their main diet. The fish and squid feed on other nekton or on the zooplankton, which in turn feeds on phytoplankton. Time must intervene and transport of the biota takes place between enrichment of the surface waters and the production of feed for the tuna.

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[3] They are reported by Murphy and Shomura: "Longline fishing for deep-swimming tunas in the central Pacific, 1950-51." Department of the Interior, Fish and Wildlife Service, Special Scientific Report: Fisheries No. 98, May 1953.

[4] The longline fishing gear is a system of horizontal and vertical lines suspended from the surface by buoys. It is allowed to drift freely in the water during the fishing operation, which occupies most of the daylight hours. The drift of this gear is mainly determined by the movement of the upper 100- to 150-meter stratum of water, though it is also influenced somewhat by surface wind and waves. The gear usually drifts far enough for its course and direction to be determined by celestial navigation.

Therefore it is not surprising to find the tuna feeding ground displaced from the upwelling area in the direction of movement of the water in the meridional plane. However, it would be expected that the plankton, occupying an intermediate trophic level, would also occupy an intermediate geographic position. This it does according to some of our other sets of data for trans-equatorial sections. But preponderantly the peak of zooplankton abundance lies closer to the upwelling area than to the fish concentration and sometimes, as in the SMITH Cruise 11 example, it almost coincides with or even lies slightly south of center of upwelling, while the tuna are located well north of it.

This may not be as anomalous as it appears at first sight. Our plankton catches are proportional to the standing crop. The standing crop, in turn, is the product of inter-action between replenishment and losses from mortality, including particularly consumption by other forms in a given water mass. As a consequence the plankton concentration should everywhere be lower than at its center of production, which in the present instance appears also to be the center of upwelling. Simultaneously with the drift of plankton away from the production center and its decline in abundance, it is passing through successional forms, some of them being successive stages in development of individuals, others being successive stages in a food chain. If we may postulate that particular successional forms of zooplankton are required by the particular nektonic forms which constitute forage for the tuna then we have an explanation for the displacement of tuna away from the center of plankton production. Unfortunately we have not yet learned how to sample quantitatively the nekton of tuna-forage size or to learn its feeding habits, and this explanation remains conjectural.

North of the concentration of tuna in the convergence zone lies the equatorial countercurrent marked by elevated surface temperature, upward tilting from south to north of the thermocline (Figs. 6A and 7B) and the eastward drift of longlines (Fig. 6B). Here the surface layers are poor in phosphate (Fig. 7C) and the zooplankton catches are also poor (Figs. 6C and 7B). However, near the northern boundary of the countercurrent, the upper portion of the thermocline, roughly located by the 26.7°C (80°F) isotherm, lies only 50 meters below the surface and water from the thermocline layer might occasionally be stirred by the wind into the overlying warm layer. Possibly such stirring accounts for the distribution of properties found by the Carnegie as depicted by Sverdrup, Johnson, and Fleming ("The Oceans", Fig. 198, p. 710) and interpreted by them to indicate upwelling at the northern boundary of the countercurrent. Some of our hydrographic sections contain indications of enrichment at this location, but the indications

are feeble and do not appear regularly as should be true if upwelling at the northern boundary of the countercurrent were a fundamental part of the circulation.

The surface upwelled water immediately south of the equator may move northward across the equator or it may move southward away from the equator depending on wind direction. At the time of SMITH Cruise 11, the phosphate values, the temperatures, and the plankton catches suggest that it was moving southward away from the equator. There is no evidence of convergence and indeed Cromwell's model calls for none south of the equator unless winds blow from the north as well as from the east. Without convergence, the biota produced in the water drifting south from the center of divergence, upwelling, and enrichment may simply disperse without producing concentrations of tuna such as appear in the convergent zone north of the equator.

However, good catches of albacore taken by our research vessels on several occasions between 5° and 17°S. latitude, suggest that the southward drifting biota may not always completely disperse before high trophic levels are reached.

We may conclude from our examination of the distribution of physical, chemical, and biological properties of sea water in the meridional plane across the equatorial current system at 155°W. longitude: (1) divergence at the equator is induced by easterly winds; (2) upwelling associated with the divergence brings inorganic nutrient salts to the surface layers; (3) plankton develops in the enriched water; (4) the enriched water bearing the plankton moves away from the equator; (5) convergence may occur either north or south of the equator depending on the meridional component of the wind direction; (6) with a northward meridional component, as in southeast trade winds, the convergence is north of the equator; (7) enhanced productivity resulting from equatorial divergence, coupled with the concentrating effect of convergence on the biota as it passes through the successive trophic levels, provides a feeding ground for tuna in the convergent zone; (8) yellowfin tuna concentrate abundantly on this feeding ground.

Turning away from the meridional aspect and remembering that the divergence-convergence system described above will be most effective when there is a strong, steady wind of long reach from an easterly direction, we may examine the east-west distribution of elements pertinent to equatorial productivity. In August, when southeast trade winds are best developed over the equator, the wind conditions for divergence and upwelling are at their best in the eastern half of the Pacific as may be seen from Fig. 8A. Arrows representing wind vectors are shown for the tier of five-degree squares lying on each side of the equa-

tor. These are drawn proportional to the weighted mean resultant travel of the wind. The arrows are longest and travel most nearly from the southeast between 100° and 150°W. longitude. Farther west they lose much of their strength and most of their northward component.

Note also that the winds themselves are divergent in the eastern part of the Pacific and become convergent in the western half. The effect of this equatorial wind divergence on the water has not been studied by oceanographers as far as I am aware. In the absence of a deflecting force at the equator and assuming there is no pressure gradient, the transport of the water should be in the direction of the wind and the wind divergence itself should produce water divergence at the sea surface along the equator east of 180° (and convergence west of 180°). It is not known how strong this effect may be, but any divergence induced directly in this manner should reinforce and strengthen the divergence caused by the forces considered in Cromwell's model.

The east-west trend of plankton abundance is consistent with the results expected from the pattern of the equatorial winds. As shown in Fig. 8B the better catches were made east of 150°W. longitude and there is a decided decline from there toward the west. However, to gain enough material to plot plankton by latitude we have had to combine all seasons of the year over an arbitrary span of latitude and we cannot rely on these data to faithfully show the finer details of plankton distribution.

Similarly the material on yellowfin tuna is not sufficient to consider August alone as was done with the wind data. In Fig. 8C, however, the combined results of a group of fishing cruises during the months of July to November are charted with shading proportional to the catching rate. As expected from the meridional aspect of equatorial circulation the center of abundance is displaced northward from the equator and as expected from the fact that the divergence-convergence structure is contained within the westward flowing South Equatorial Current, it is also displaced to the west of maximum divergence as judged from wind pattern and plankton concentration. The relatively small displacement northward is consistent with the relatively weak meridional circulation and the large displacement westward is consistent with the very much stronger zonal circulation.

In assembling the above materials bearing on equatorial productivity and on the mechanisms involved, I have been highly selective. In part this selectivity has been purposeful and intended to emphasize the major elements of the productivity system. In part the selectivity has been imposed by incompleteness of available information. It should be noted particularly that the meridional aspect was portrayed by a

specific example, and zonal aspect by averages exemplifying a particular period of the year. For neither aspect have I indicated the variability in location and magnitude of the various elements of the system. Likewise there are neglected the peculiarities which crop up in each set of data collected. This portrayal therefore is certainly much distorted in the direction of over-simplification and most probably distorted to an unknown degree in the direction of specific peculiarities of the particular sets of data employed. When more complete data are at hand and when there has been a more thorough study, a different and probably more complex concept will be necessary.

In the meantime there appears to be very complete agreement in the gross features of equatorial circulation, of plankton distribution, and of fishing ground location as to time, place, and relative magnitude. The correspondence is such as to leave little doubt that the yellowfin tuna stock south of Hawaii owes its existence to and is nourished by the equatorial current system.

Perhaps of interest equal to the facts themselves is the demonstration that a rich fishing ground may be discovered through the scientific study of the particular features of ocean circulation pertinent to the existence of fish stocks.

It is, of course, obvious that the attainment of the present degree of understanding has resulted from the participation of a considerable number of persons ranging in specialization from expert fishermen to senior scientists united in a concerted drive toward a common objective. Milner B. Schaefer, John L. Kask, and Donald L. McKernan have successively led the scientific team. Townsend Cromwell, until recently, has been in charge of the oceanographic program; Joseph E. King has been the chief researcher on plankton and on the food of tuna; while Fred C. Cleaver initiated, and Garth I. Murphy has carried on, the longline fishing surveys. I am especially grateful to our present oceanographer, Thomas S. Austin, for invaluable assistance in assembling the materials for this report.

ILLUSTRATIONS

FIGURE 1.—Hydrographic stations occupied by the U.S. Fish and Wildlife Service vessel HUGH M. SMITH for the investigation of equatorial circulation, January 1950 to February 1953.

FIGURE 2.—Longline fishing stations occupied by the U.S. Fish and Wildlife Service vessels HUGH M. SMITH, JOHN R. MANNING, and CHARLES H. GILBERT, and the M/V CAVALIERI (chartered) for investigating the distribution of tuna, October 1950 to March 1953.

FIGURE 3.—Direction of current transport (Small solid arrows), which would exist near the equator under various wind conditions, were there no pressure gradient force acting. The current magnitude is drawn everywhere constant (small solid arrows). For each wind condition (large solid arrows) the meridional components of the current transport (dotted arrows) are drawn to emphasize the regions of meridional divergence (Div.) and convergence (Conv.). From Cromwell's ms. Figure 6.

FIGURE 4.—The Fish and Wildlife Service research vessel HUGH M. SMITH, a tuna-clipper type to which have been added laboratory, winches, and other special instruments for oceanographic research.

FIGURE 5.—Location of the hydrographic and the fishing stations of HUGH M. SMITH Cruise 11, August 20 to October 6, 1951.

FIGURE 6.—Diagrams of certain data resulting from the southbound passage on HUGH M. SMITH Cruise 11 along the 150th west meridian, August 24 to September 25, 1951. A. Temperature section showing the water layer warmer than 26.7°C (unshaded), between 26.7°C and 15.6°C (shaded) and colder than 15.6°C (black), as taken from bathythermographs. B. Direction of drift of longline gear at each fishing station. C. Volume of zooplankton taken in a plankton net of one meter in diameter at the mouth and towed obliquely for approximately one-half hour through the upper 200 meters of water in the daytime. Volumes were measured by displacement and adjusted to a standard quantity of 1000 cubic meters of water strained based on flow determined by a current meter installed in the mouth of the net. D. Rate of catching yellowfin in number per hundred hooks per day fishing as determined by fishing 40 baskets of gear each comprised of 210 fathoms of longline suspended by 10-fathom floatlines and bearing 6 hooks spaced 30 fathoms apart and suspended by 10-fathom droppers.

FIGURE 7.—Diagrams of certain data resulting from the northbound passage on HUGH M. SMITH Cruise 11 along the 150th west meridian, September 25 to October 4, 1951. A. Temperature at the sea surface. B. Temperature section showing the water layer warmer than 26.7°C (unshaded), between 26.7°C and 15.6°C (shaded) and colder than 15.6°C (black), as taken from bathythermographs. C. Phosphate section showing water with less than 0.4 microgram atoms per liter (unshaded) between 0.4 and 1.0 microgram atoms per liter (shaded) and more than 1.0 microgram atoms per liter (black). D. Volume of zooplankton taken and treated as stated in the title of Figure 6, except that the hauls were made at various hours of the day and night and received further adjustment for diurnal variation according to the formula: V_a = antilog

(log V + 0.1 sin t) where V_a is the adjusted volume, V the unadjusted volume, and t the angle of rotation of the hour hand on the 24-hour clock at the time of the mid-point of the hauling period, with zero rotational angle such that the angle whose sine is 1.0 occurs at midnight and −1.0 at noon.

FIGURE 8.—Diagram of wind vectors, plankton abundance, and tuna distribution in the equatorial zone. A. Resultant wind vectors were computed as the weighted means of frequency and speed from the several compass points for 5-degree squares bordering the equator as published in U.S. Hydrographic Office Pilot Chart for the North Pacific for August 1952, the arrows point in the direction of travel and their shafts are proportional to the weighted mean speed. B. Mean plankton volumes at several longitudes computed as the mean of all hauls taken from between latitudes 5°S to 10°N at or near the given longitude. C. Distribution of yellowfin tuna in the mid-Pacific equatorial region as estimated from longline catches. The lightest stipling represents less than 3 yellowfin tuna per hundred hooks, the heaviest represents more than 9 per hundred hooks and the intermediate stipling represents intermediate catching rates. For orientation as to location and area there is given by light stipling the area of the Japanese prewar longline fishery and by dashed outline the area of the American west coast live bait and purse seine fishery for yellowfin and skipjack tunas.

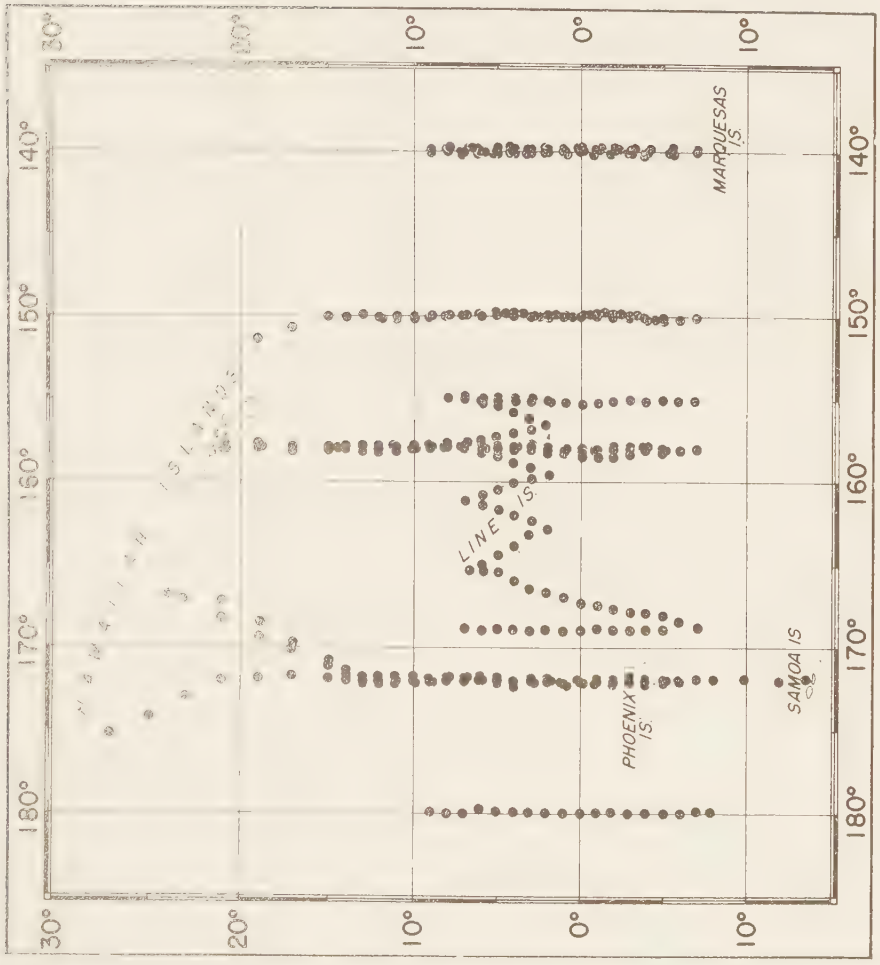
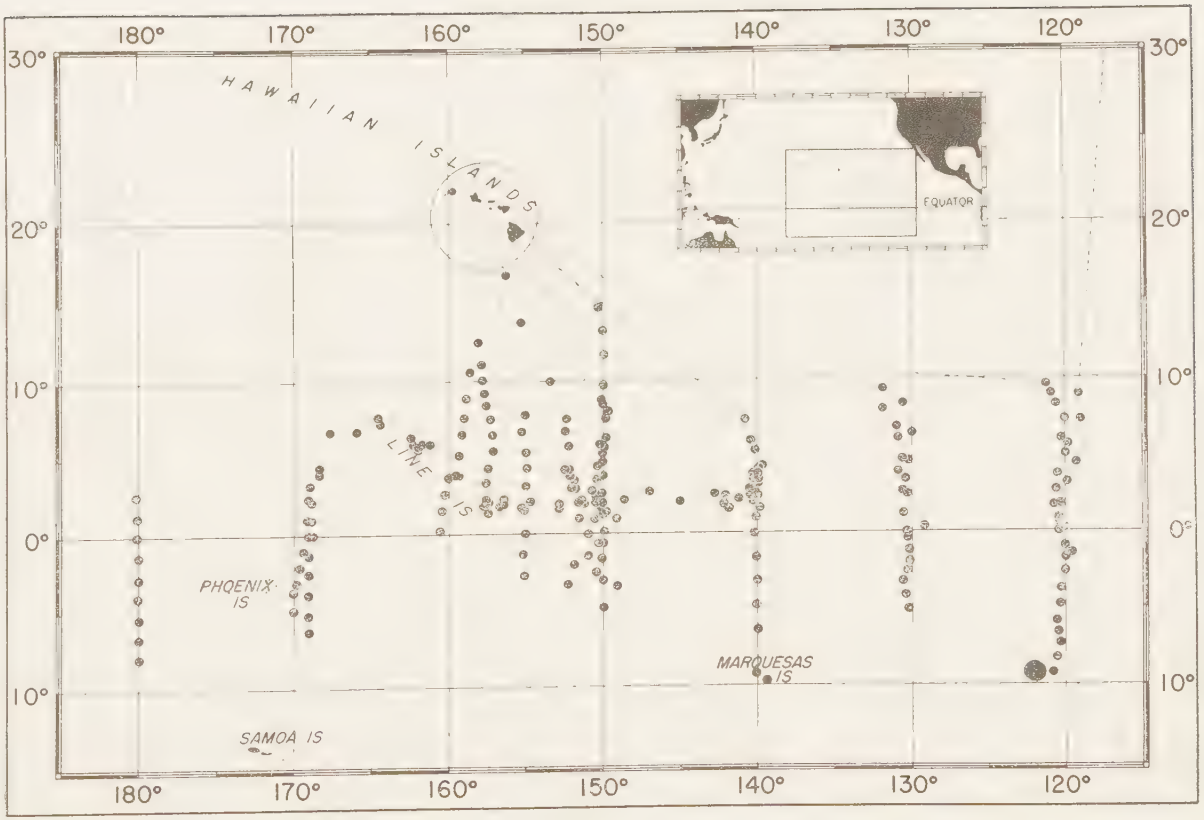

30°
20°
10°
0°
10°
180°
170°
160°
150°
140°
MARQUESAS IS.
LINE IS.
PHOENIX IS.
SAMOA IS

FIGURE 1



EQUATORIAL LONGLINE FISHING CRUISES

FIGURE 2

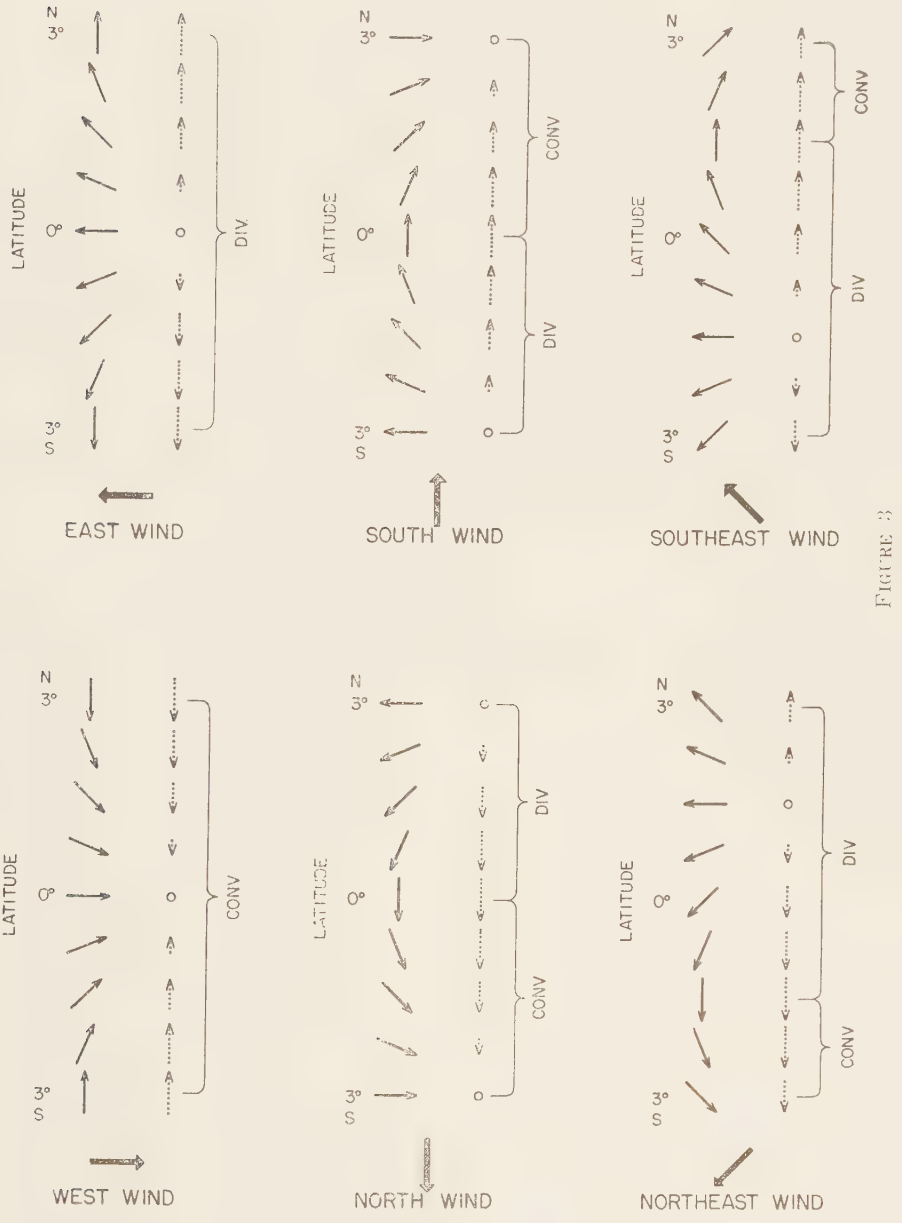

N
3°
LATITUDE
0°
S 3°
DIV
CONV
EAST WIND
SOUTH WIND
SOUTHEAST WIND
WEST WIND
NORTH WIND
NORTHEAST WIND

FIGURE 3

FIGURE 4

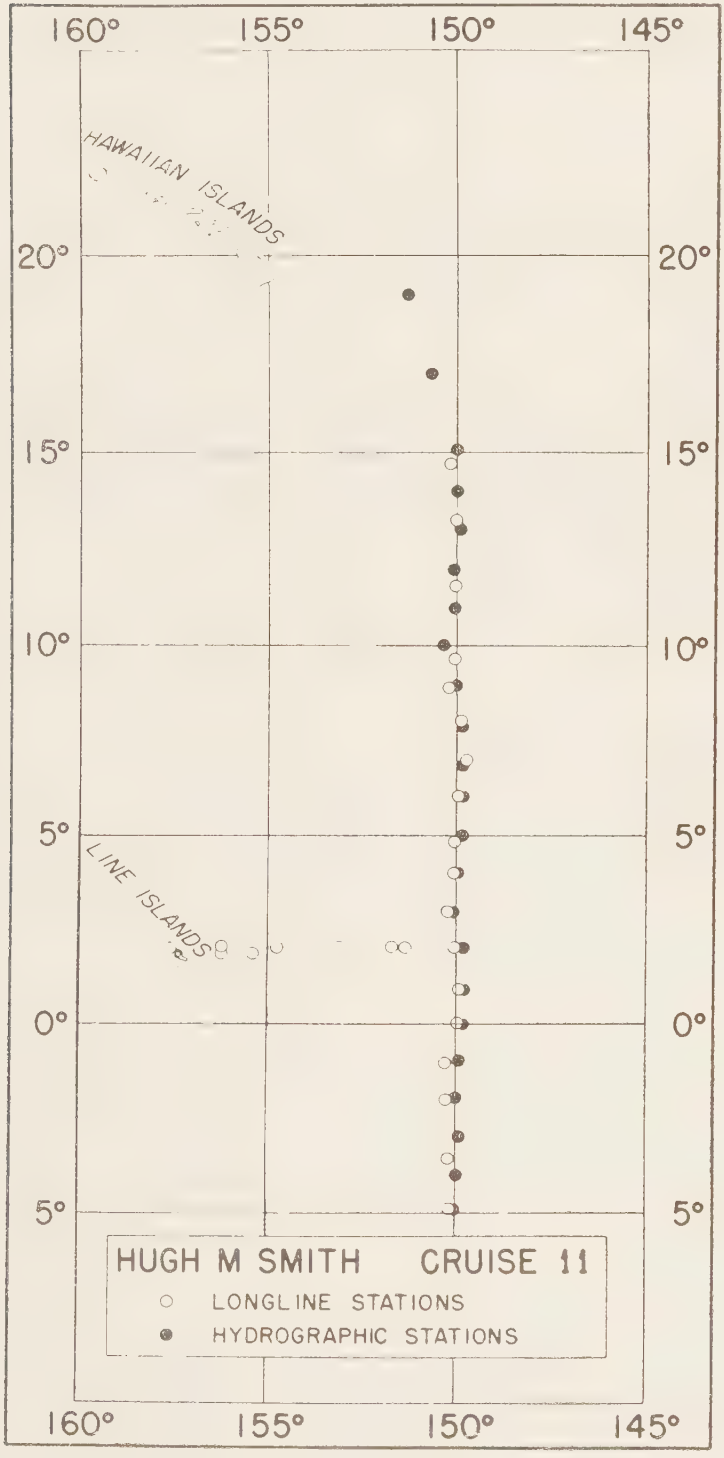

160°
155°
150°
145°
HAWAIIAN ISLANDS
20°
15°
10°
5°
0°
5°
LINE ISLANDS
HUGH M SMITH CRUISE 11
LONGLINE STATIONS
HYDROGRAPHIC STATIONS

FIGURE 5

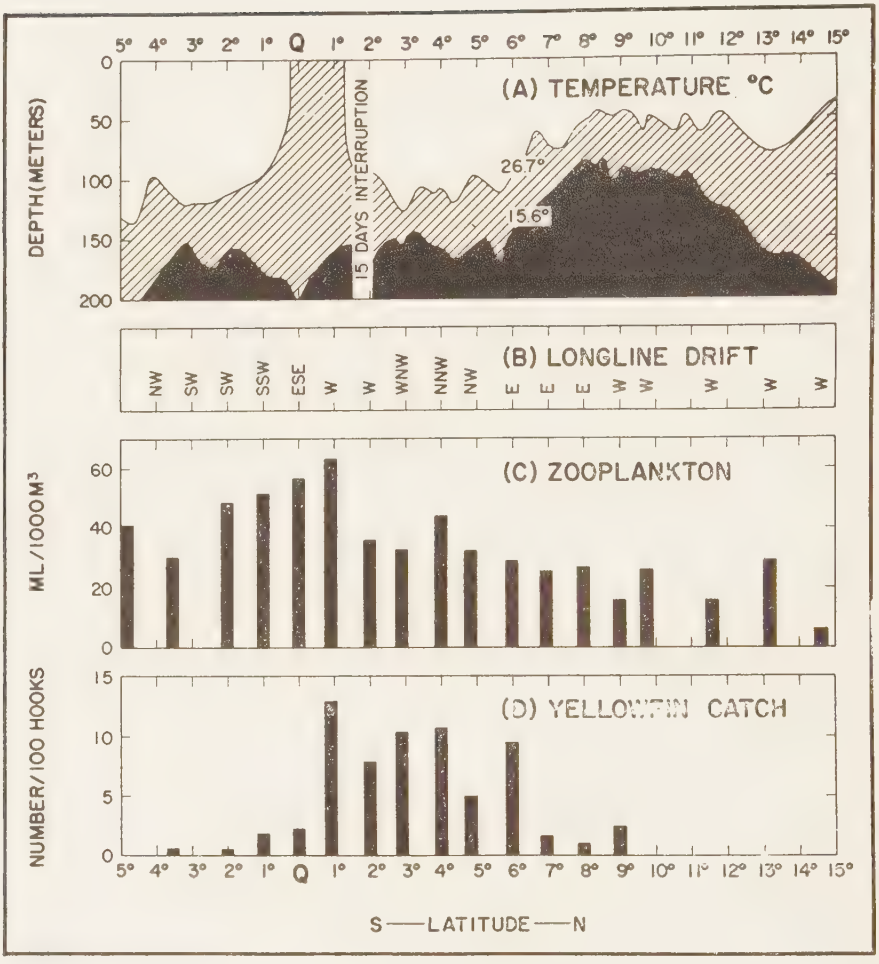

5° 4° 3° 2° 1° Q 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° 13° 14° 15°
DEPTH (METERS)
0
50
100
150
200
(A) TEMPERATURE °C
26.7°
15.6°
15 DAYS INTERRUPTION
(B) LONGLINE DRIFT
NW SW SW SSW ESE W W WNW NNW NW E E E W W W W W
(C) ZOOPLANKTON
ML/1000 M³
60
40
20
0
(D) YELLOWFIN CATCH
NUMBER/100 HOOKS
15
10
5
0
5° 4° 3° 2° 1° Q 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° 13° 14° 15°
S——LATITUDE——N

FIGURE 6

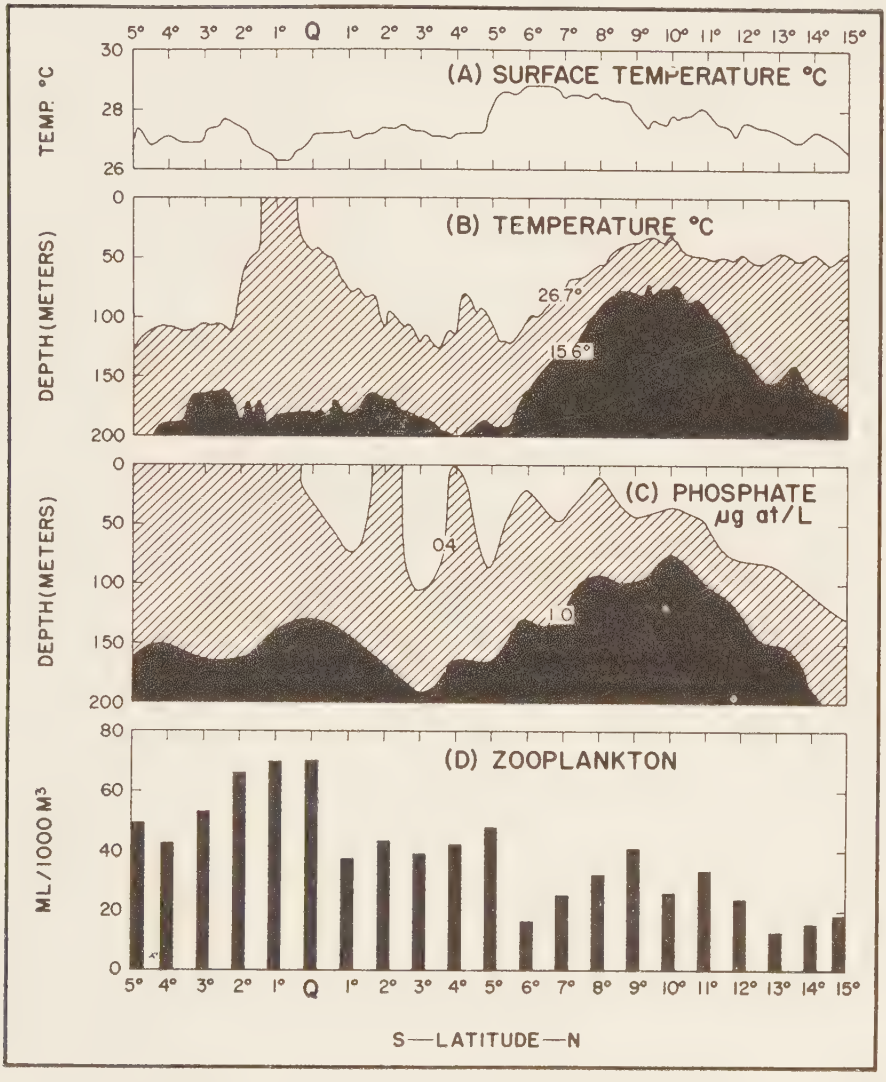

5° 4° 3° 2° 1° Q 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° 13° 14° 15°
TEMP. °C
30
28
26
(A) SURFACE TEMPERATURE °C
DEPTH (METERS)
0
50
100
150
200
(B) TEMPERATURE °C
26.7°
15.6°
(C) PHOSPHATE
µg at/L
0.4
1.0
ML/1000 M³
80
60
40
20
0
(D) ZOOPLANKTON
S—LATITUDE—N

FIGURE 7

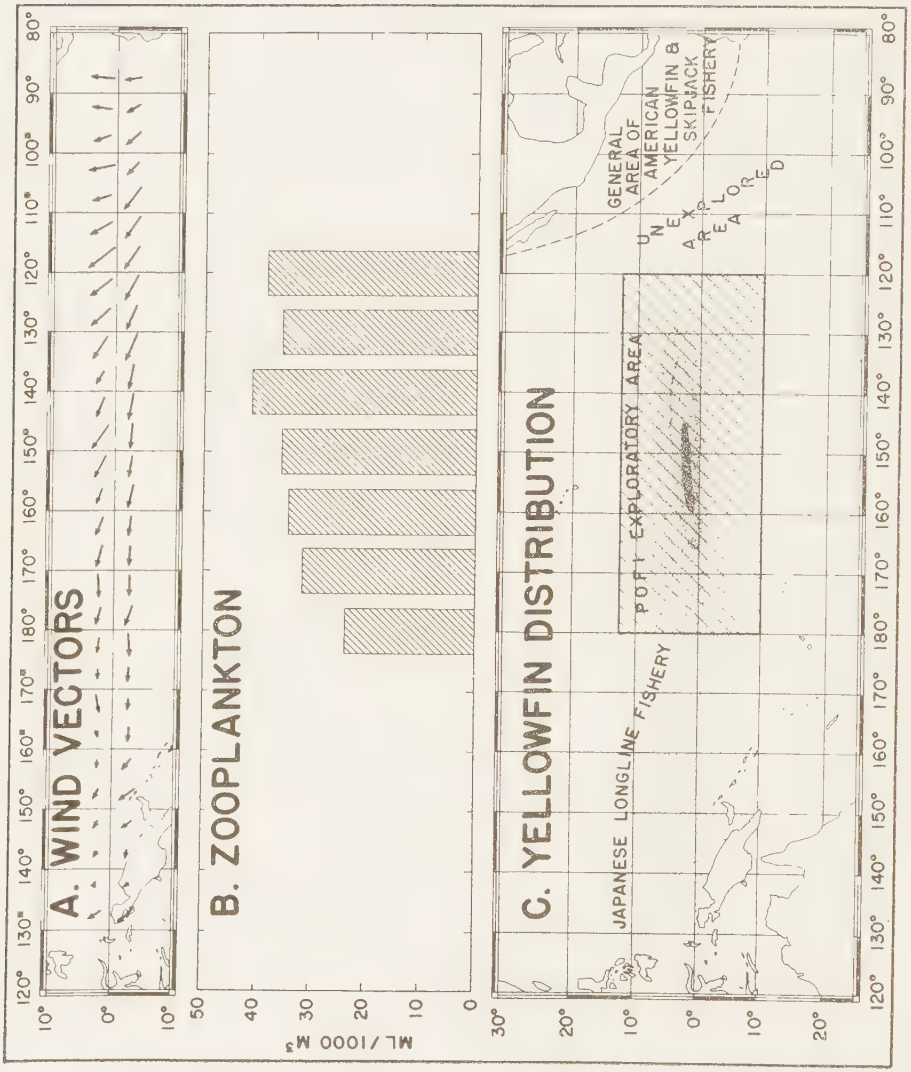

A. WIND VECTORS
B. ZOOPLANKTON
ML/1000 M³
C. YELLOWFIN DISTRIBUTION
JAPANESE LONGLINE FISHERY
PORT EXPLORATORY AREA
GENERAL AREA OF AMERICAN YELLOWFIN & SKIPJACK FISHERY
UNEXPLORED AREA

FIGURE 8

DEVELOPMENT AND CONSERVATION OF THE TUNA FISHERIES OF THE PACIFIC

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Scripps Institution of Oceanography
La Jolla, California, U.S.A.

In recent years, it has often been pointed out that in order to keep up with the food demands of a growing population, man must turn to the sea as a major source of protein food. In point of fact, the utilization of the food resources of the sea has been increasing at a rapid rate for some decades. With the development of steam propulsion for fishing craft late in the last century, followed by the development of diesel engines, the sea fisheries have expanded rapidly in scope and intensity of fishing. At the same time, improved techniques of preserving and transporting fish have broadened the market for the catches. This expansion of the fisheries has been most rapid, of course, in those seafaring nations whose technological development is most advanced (Canada, the United States and Japan in the case of the Pacific Ocean). Other nations, however, have also participated in the development, and there is, at present, considerable time and money being expended by various agencies to assist the nations with little development of fisheries to expand them by the application of modern technological advances imported from other areas, or by the forced evolution of their indigenous methods.

Because of problems of preservation of the catch, as well as economic factors, the fisheries closest to the ports of landing tend always to be most heavily exploited. Furthermore, the hazardous nature of seafaring, with the consequent need for larger and more costly craft to exploit distant oceanic fishing areas, favors the development of the inshore fisheries. In consequence, many of the demersal and inshore fish populations are now fully or nearly fully exploited. The Pacific salmon fisheries, for example, are certainly not capable of any increase in catch, except as better management may increase somewhat the efficiency of utilization of the populations of these species. The Eastern Pacific halibut stocks are controlled by scientific management, having been overfished in the 1920's and 1930's. The formerly large fisheries for sardines have declined both on the western and eastern sides of the Pacific. There is some question as to how much of the decline of the

sardine catch is due to fishing, and how much is to be attributed to changes in the oceanic environment; but there seems to be no question that the populations of this species have no possibility of supporting a much greater catch than has been attained in the past. The herring fisheries of the North Pacific, on both sides of the ocean, seem to be rather fully exploited. The great Japanese trawl fisheries of the East China Sea and adjacent areas have been so heavily fished that they are now subject to regulation to curtail the intensity of fishing. Certainly there are yet demersal and inshore fish stocks that are little utilized, such as the hake and pollock of the Northeastern Pacific. In the main, however, the new frontier of commercial fishing is the exploitation of the oceanic fishes of the high seas.

The potential food production from fisheries of the high seas is doubtless very large. The cost of harvesting this crop is, however, also large. Under present economic circumstances, therefore, development of high sea fisheries is confined to those species which occur in high local concentration and have a relatively high unit value, so that the catch per unit of fishing effort has sufficient value to offset the high cost of production. Few pelagic oceanic organisms meet these requirements at the present time. The whales are, of course, an outstanding example. Among the fishes, the tunas support one of the few major fisheries of the high seas in the Pacific. The several species of tunas aggregate in sizable schools, occur in relatively large concentrations in certain areas of the sea, and command a high market price. They have, therefore, become the object of increasingly extensive and intensive fisheries.

Tuna Fisheries of the Pacific

Five kinds of tunas are the objects of important commercial fisheries in the Pacific. They are:

Albacore—*Thunnus germo*
Yellowfin—*Neothunnus macropterus*
Skipjack—*Katsuwonus pelamis*
Bigeye—*Parathunnus sibi*
Bluefin—*Thunnus thynnus, T. orientalis, T. maccoyi*

Several other species support fisheries of a local nature and of minor importance, including *Kishinoella tonggol*, the northern bluefin of Australia, and the several species of *Euthynnus*. The bonitos, genus *Sarda*, which support important fisheries, are not usually considered tunas in the strict sense.

The fisheries for tunas in the Pacific have developed rapidly during the last three decades, and at present are among the most valuable fisheries of this ocean. In the United States, the tunas rank first in

total value of all categories of fish products. In Japan, they are of major importance both for domestic use and for export. They support an important industry in Peru, and are of growing importance in Australia. It is, perhaps, most convenient to consider the development and present status of the fisheries by species.

Albacore

The albacore (*Thunnus germo*) occurs in commercial quantities in temperate waters of both northern and southern hemispheres. Tuna fishing in the Eastern Pacific had its inception in the first decade of this century in Southern California, where albacore occur during the summer and fall months in inshore surface waters, where they may be captured by trolled lures or by pole and line, using live bait for chum. Small craft, fishing only a few miles from shore, supplied the infant canning industry. Since the fishing depended on the seasonal occurrence in inshore water of an oceanic, migratory fish, availability was notably erratic from year to year. By 1925, however, the fishery produced 22 million pounds of albacore. In 1926 the albacore failed to appear in appreciable numbers, and the landings dropped to two-and-a-half million pounds. They continued scarce for a decade in waters of California and Baja California covered by the tuna fleet. The erratic and seasonal occurrence of albacore led the fishermen to turn to the tropical tunas, the yellowfin and skipjack, which range north to California during the summer, and to extend their operations southward, first off the Mexican coast and later farther south, in order to extend the season of fishing and to find greater concentrations of these species. The failure of the albacore fishery in 1926 gave tremendous impetus to the development of the fishery for tropical species, which will be discussed further below.

In 1936, albacore began to appear again in greater numbers in California inshore waters, and have since continued to support an important amount of fishing. In 1937, fishermen off Oregon, Washington, and British Columbia discovered that albacore occurred there, too, in the summer at some little distance offshore, and began to fish for them. They have continued to do so since.

The present albacore fishery of the Eastern Pacific extends from Baja California to British Columbia, being pursued only during the summer and fall months when the fish appear in surface schools in waters not far from shore, and can be captured by trolling lures or by pole and line using live-bait chum. Some fishing is done as far as 150 miles from the coast, but most of it is done within a much narrower range. Albacore are known, from observations of research vessels, to occur a good deal further offshore than they are now fished. Because

of the dependence of the fishery on the seasonal, inshore occurrence of the fish, which varies a good deal from year to year, probably in response to variations in oceanographic factors, the success of the fishery varies widely, the variability increasing as one goes north. Present magnitude of the fishery is indicated by the statistics for 1950, when 73 million pounds were landed, 62 million of these in California.

On the western side of the Pacific, tuna fishing is much older. Fishing for tunas in the waters adjacent to Japan has been engaged in by fishermen of that nation since ancient times. Not until the introduction of motorized fishing vessels in the first decade of the present century, however, did the fishery begin to assume any large proportion, so that the development of the modern fishery is contemporary with that of the Eastern Pacific.

The "summer" albacore fishery, in the adjacent seas of Japan, is similar to the fishery in the Eastern Pacific. It depends on schools of fish which appear in inshore waters about April or May, reach their greatest abundance in about June, and disappear in the late summer or fall.

Albacore, and other tunas as well, are also fished in Japan in subsurface waters by means of floating long-lines. The long-line fishery for albacore has, as a result of explorations by Japanese research vessels, been extended eastward to the longitude of the Hawaiian Islands. The long-line fishery has its greatest success during the winter months and appears, according to Uda and Tokunaga (1937), to be most productive in the region of the North Pacific convergence near latitude 30°N.

Albacore is not a preferred species for domestic consumption in Japan, but finds a ready market in the United States. Therefore, much of the catch is exported either as canned tuna, or as frozen tuna which is canned in the United States. The Japanese albacore catch in 1950 amounted to 65 million pounds, and was nearly double that amount in 1952.

Small quantities of large albacore are captured on long-lines by the local fishery in the Hawaiian Islands, incidental to fishing for yellowfin and bigeye tuna. Small commercial quantities are fished off Chile and southern Peru.

The albacore fisheries of the Pacific appear to be capable of considerable expansion, both by development of fisheries in the southern hemisphere, which are now little exploited, and by further offshore development of the North Pacific fisheries. Exploration of the offshore distribution of albacore in the Northeastern Pacific is planned to be undertaken during the coming winter by agencies of the U. S. Govern-

ment and the State of California, so development of an offshore fishery in this area may not be far distant.

Bluefin

These are tunas of temperate waters, occurring in both the northern and southern hemispheres. Commercial fisheries are conducted for them off California, Japan and southern Australia (Sydney to Tasmania). The bluefin tunas of these three regions are probably distinct species (*Thunnus orientalis* of Japanese waters, *T. thynnus* in the Eastern Pacific, and *T. maccoyi* in the Australian area), according to morphological data of Godsil and Holmberg (1950), although some taxonomists, for example Fraser-Brunner (1950), place them all in a single cosmopolitan species. In any event, it seems quite certain that the three groups being fished in the Pacific are quite distinct from one another.

The bluefin of California waters is taken commercially only by purse seines. The fishery is normally confined to the summer months, June to September, with best fishing in July and August when the schools of fish appear near the surface in waters not far from shore. The supply is erratic from year to year, and average total production is small, and highly variable, between 3 million and 22 million pounds in various years of the past decade.

The Japanese fishery for bluefin tuna is also pursued mainly in oceanic waters within a hundred miles or so of land, by means of nets, traps, and long-lines. A considerable catch is made with nets and traps close to the shore in certain regions. Some bluefin are, however, taken by long-lines, incidental to fishing for other species, on the high seas many hundreds of miles from land. Available statistics on bluefin tuna landings in Japan indicate that there, also, the production is erratic, varying irregularly between 2 million and 52 million pounds in various years from 1936 to 1951.

The Australian representative of the bluefin tuna, unlike that of the California fishery, bites readily on both trolled lures and live bait. According to Serventy (1941) these are small, immature fish ranging from 6 to 35 pounds in weight. The fishery is conducted by small vessels during the summer months in inshore waters. Presumably the larger, adult fish occur elsewhere. Until 1951, fishing was done by trolling only. In that year a live-bait vessel conducted fishing trials with some success, and in 1952 and 1953 a small fishery has been prosecuted using the live-bait, pole and line technique.

It appears that the Australian fishery, which now produces only a few hundred tons per year, is capable of considerable expansion. Prospects for increased production in other areas are not possible to

estimate at this time, in the absence of adequate information on the distribution and biology of fish involved.

Yellowfin

The yellowfin tuna (*Neothunnus macropterus*) is a tropical species occurring everywhere in Pacific equatorial waters between approximately, the surface isotherms of 18°C. It is the object of a large fishery on both sides of the Pacific Ocean and in the Central Pacific westward of the International Date Line. Considerable stocks, not now exploited, are known to exist in the eastern equatorial Pacific between the International Date Line and the presently fished seas adjacent to the American West Coast.

As noted previously, the fishery for the tropical tunas began in California shortly after the initiation of fishing for albacore. The seasonal and erratic nature of the albacore fishery led the fishermen and canners to turn to the tropical yellowfin and skipjack tunas. The fishery began as a seasonal one in waters of Southern California and Northern Baja California, but the fishermen soon learned that by going farther south yellowfin and skipjack could be taken during a greater part of the year, more regularly, and in greater abundance. This stimulated the building of large vessels which could stay at sea longer and range further from port. The failure of the albacore fishery in 1926 gave strong impetus to the expansion of the tropical tuna fishery. By 1930 vessels were fishing regularly far down the Mexican coast, and beginning to venture even farther south.

As the vessels ventured further into the tropics on longer voyages, problems of preserving the catch multiplied. During the 1930's experiments were made with mechanical refrigeration, and finally brine freezing of the fish was developed. At the same time, the vessels evolved into large craft of the high seas capable of operating thousands of miles from home on long voyages. By 1938 vessels from California ports were operating over the entire area from Southern California to Ecuador, and offshore over 200 miles. The outbreak of World War II curtailed sharply the long range fishing, because many of the larger vessels were converted to military duty and various restrictions were placed on the operations of the remaining vessels. With the cessation of hostilities, however, the fleet again grew rapidly and prosecuted the fishing even more vigorously. The long range fishery has been extended to northern Peru, and provides now an even greater share of the catch than before the war.

This fishery by United States vessels produces by far the major part, over 90%, of the catch of yellowfin, as well as of skipjack, tuna taken in the Eastern Pacific. Small local fisheries developed during

the 1920's and 1930's in Mexico and Costa Rica. During the war, with the increased demand for tuna in the United States, a local fishery was started in Peru for yellowfin and skipjack tunas, and this continues to be an important part of the Peruvian fishing industry, greatly exceeded in production, however, by the fishery for bonito. Recently a small local fishery has been initiated in Ecuador.

The growth of the production of yellowfin tuna from the Eastern Pacific is illustrated in Figure 1, in which the production of skipjack is also depicted. These two tropical tunas are taken in the same waters on the same voyages. The very rapid postwar growth of the fishery is evident from this chart. There is evidence that the production of yellowfin is no longer increasing, but the upward trend of skipjack production is being maintained.

Over 75% of the yellowfin and skipjack tunas taken in the Eastern Pacific are captured by means of pole and line, live bait being employed to chum the tunas to the vessel and to induce them to strike the lures. Bait fishes are several species of small fishes, mostly of the families *Clupeidae* and *Engraulidae*, captured in the territorial waters of the several countries bordering on the Eastern Pacific. The remainder of the catch is made by means of purse seines. These methods capture only the surface-schooling component of the population. No commercial fishery has been developed for the large, old yellowfin tuna, analogous to the Japanese and Hawaiian long-line fisheries.

A parallel, but geographically even more extensive, development of the yellowfin tuna fishery has taken place in the Western Pacific Ocean. Yellowfin tuna occur during the summer months in Japanese home waters, and for many years have been fished there by nets, long-lines, and pole and line, but did not contribute an important share of the tuna catch until the southward expansion of the 1930's.

Surveys by government vessels and commercial companies, about 1931, discovered that yellowfin tuna and bigeye tuna (*Parathunnus sibi*) are distributed throughout the tropical southwest Pacific, and can be taken commercially in sub-surface waters of the high seas by means of long-lines. This led to the initiation of a commercial fishery which was, of course, very soon terminated by World War II. Immediately following the war, the Japanese fishery expanded back into this area as rapidly as permitted by the Occupation authorities. This fishery is still expanding, and at the present time operates throughout the tropical western Pacific as far east as the Phoenix Islands and south to the Coral Sea, Arafura Sea and Banda Sea. This long-line fishery captures, in addition to yellowfin tuna, quantities of bigeye tuna, spearfishes, and sharks. The tunas captured by this means are mostly very large fish, a good deal larger than those taken at the surface. Available recent

records of the Japanese fishery indicate that it is annually producing about 30 million pounds of yellowfin tuna and a similar quantity of bigeye tuna, with the catch increasing year by year.

Fishing of surface schooling yellowfin tuna is not extensive in the western Pacific. During the 1930's the Japanese developed a moderately large fishery for surface-schooling skipjack in the Caroline, Marshall, and Marianas Islands, employing the live-bait technique. Small quantities of yellowfin were taken incidentally. This fishery depended, of course, on supplies of live bait which are not extensive in the Mandated Islands (now the Pacific Trust Territories), and which have not been available to Japanese fishermen since the war. Except for local subsistence fishing by islanders of the Trust Territories, and some fishing, mostly by means of traps, in the Philippines, the tuna fishery of the western tropical Pacific is almost exclusively a long-line fishery at the present time.

There is also a small fishery for yellowfin tuna and bigeye tuna in the immediate vicinity of the Hawaiian Islands. During the summer months, skipjack tuna are taken by live-bait techniques from surface schools, and a few yellowfin are taken incidentally. The main catch of yellowfin, however, is made by long-lines, which capture large sub-surface tunas, averaging over 100 pounds each. The catch is almost entirely marketed for local consumption as fresh fish, and, hence, the volume is limited by the local market. The catch is about two million pounds a year, two-thirds of it being yellowfin and one-third bigeye.

Research by the Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service, during the past three years, has demonstrated that large concentrations of sub-surface yellowfin and bigeye tunas are to be found in equatorial waters of the Central and Eastern Pacific, east of the present Japanese fishery. Greatest concentrations occur between the equator and the southern boundary of the counter-equatorial current, being associated with a zone of current convergence in those latitudes. Sizable surface schools have also been observed in the vicinity of the Line Islands and Phoenix Islands. It has also been demonstrated by various commercial explorations that surface-schooling yellowfin occur in some numbers in the Marquesas, Societies, and Tuamotus. These stocks of yellowfin are at present not fished commercially.

It would appear that the yellowfin tuna production from the Pacific Ocean will continue to increase, both by expansion to presently unfished areas and by further increase in production from some regions now being fished.

Bigeye

The bigeye tuna, *Parathunnus sibi,* is fished in the same regions as the yellowfin tuna, and by the same gear. It constitutes an important

part of the long-line catches, as noted above. Occurrence in surface schools is less frequent, so that this species is an incidental and insignificant part of the catch where surface fishing, using live bait or by purse seines, is the means of production.

In the Eastern Pacific fishery along the coasts of the Americas, the few bigeye captured are included with the yellowfin in the catch statistics. The exact percentage of bigeye included is not known, but examination of landings on a sampling basis indicates it is not large, probably not over 2 or 3 per cent.

Skipjack

As indicated above (pp. 154–155) the skipjack, *Katsuwonus pelamis*, occurs in surface schools in the region of the Eastern Pacific fishery in the same general localities as the yellowfin. It occurs sometimes in pure schools and sometimes in mixed schools with yellowfin of similar size. It is fished both by live bait and by purse seine, just as is the yellowfin.

The development of the fishery for yellowfin and skipjack in the Eastern Pacific has already been described. The growth of the skipjack catch is shown with that for yellowfin in Figure 1. Although both species have been fished since the initiation of the fishery, yellowfin has been the preferred species, commanding a higher price and being somewhat easier to preserve, particularly before the days of brine freezing. In consequence, the expansion to distant areas during the 1930's was directed primarily at the yellowfin tuna. The postwar growth of the fishery has, on the other hand, depended on skipjack to an increasing extent. It appears that with the increasing exploitation of the yellowfin stock of the Eastern Pacific, and the inevitable accompanying decrease in catch per unit of effort, the fleet has turned increasingly to skipjack, the catch of which has, in recent years, risen a good deal in relation to that of yellowfin.

Skipjack is the most important species in the Japanese tuna fishery, the landings at the present time being over 200 million pounds per year. This species of tuna has been an important article in the Japanese diet since ancient times, but its capture was confined to coastal waters until introduction of powered fishing vessels early in this century. The offshore fishery grew rapidly thereafter, encompassing not only Japanese home waters, but regions to the south to well below the equator, and eastward through the Mandated Islands. The fish are captured almost exclusively by pole and line, using live bait for chum. Negligible quantities are taken incidentally by long-lines. Purse seining is reported to have been tried experimentally in recent years.

During the 1930's, skipjack fishing in the Caroline, Marshall, and Marianas Islands was rapidly developed, in spite of scarcity of live bait

in those areas, through combined activities of government agencies and commercial companies, until in 1937 a peak production was obtained amounting to 40 thousand metric tons. The advent of the war, of course, terminated this fishery. At present it is inactive except for local fishing by islanders on a subsistence basis.

A small fishery for skipjack occurs during the summer months in the vicinity of the Hawaiian Islands, producing, on the average, about 9 million pounds per year. The limiting factor here is the great scarcity of live bait which is required for the capture of skipjack.

Essentially unexploited regions in which skipjack are known to occur in commercial quantities include all of Oceania and the seas to the north of New Zealand, the Coral Sea, and the Arafura and Banda Seas. In addition to problems of transportation and marketing, the scarcity of live bait in part of this area deters the development of fisheries there.

Potential for Future Development

From the foregoing very brief review of the Pacific tuna fisheries, it is evident that the several species are very unevenly exploited in different parts of their range. Certain regions support rather intensive fisheries, while no fishing at all is done in others.

With the demand for tuna increasing year by year, utilization of presently unexploited and underexploited tuna stocks may be expected to follow in due course, as their exploitation becomes profitable, either as a result of increased demand, and consequently increased price, or as a result of lower harvesting costs due to improved or novel fishing methods. Certainly the potential annual harvest from the Pacific tuna fisheries is a good deal larger than that being taken at the present time.

Problems of Conservation

Since the tuna resources throughout much of the Pacific Ocean are obviously not being exploited to anywhere near their maximum yield, problems of maintaining the supply through management are, from the broad viewpoint, of secondary importance at the moment, and the interests of most tuna researchers have, consequently, been centered on problems connected with expansion and development of the fisheries. The tuna stocks are not unlimited, however, and the rapid growth of the fisheries will inevitably bring forth in the not too distant future the necessity of conservation of the stocks to produce maximum yields. The fishery for the tropical tunas of the Eastern Pacific is already sufficiently intense and some of the nations having interests in that fishery have become concerned about the possibility of the approach of overfishing.

Intensive fishing of a tuna species in one part of a large geographical area, while it is unfished in other parts, can scarcely result in overfishing if the species consists of a single large population migrating freely throughout the area. It may happen, however, that there are a number of sub-populations, so that the fishery is bearing very heavily on one or more of these while leaving the others untouched. In the latter case, the sub-populations being fished may easily be overfished while the others remain untouched.

Like much else concerning the biology and life history of the tunas, the degree of distinctness of the tuna populations of the several regions of the Pacific is imperfectly known. For the yellowfin tuna, it has been fairly well demonstrated by morphometric studies by Godsil and Greenhood (1951), Schaefer (1952) and Royce (1953) that the yellowfin tuna of the Eastern Pacific are distinct from those of other parts of the Pacific. Royce's work shows that there are also further distinctions between populations in other regions of the Pacific. For the albacore, on the other hand, morphometric comparisons of fish from the eastern and western north Pacific have, so far, failed to show significant differences, and the recent recovery off Japan of a specimen tagged off California tends to indicate that the North Pacific albacore may be a single large population. Respecting skipjack, work in progress by the author indicates that the skipjack of the region of the Eastern Pacific fishery are probably morphometrically different from those of Oceania. This work has, however, not been completed. So far as the tropical yellowfin and skipjack tunas of the Eastern Pacific are concerned, then, there is evidence to support the belief that they are distinct from those of the other regions of the Pacific, so that a very intense fishery could reach the point of overfishing.

The very rapid growth of the Eastern Pacific fishery for these species, and the very incomplete knowledge of their biology, ecology, and life history, has caused concern that the fishery could become overdeveloped, with consequent overfishing of the tuna stocks of this area. Since most of the tuna catch is made by means of live bait, there has also been concern lest the populations of bait fish be overfished with disastrous effects on the yield of tuna. This situation, obviously, requires that scientific investigations be conducted, in order to provide an adequate foundation of knowledge of the biology and ecology of the fishes concerned, and of the effect on them of the increasingly intense fishery.

Although our knowledge of the ways of life of the tunas is small, certain things we do know. We know that they are creatures of the open sea, inhabiting the reaches of the ocean beyond the territorial

limits of any nation. They spawn in the open sea far from land, the juvenile stages require no littoral nursery grounds, and the adults are completely oceanic in their foraging. Such knowledge of their movements and aggregations as we have, indicates that they are oriented to the water masses and currents of the ocean rather than to any geographical feature *per se*. The fisheries which harvest them are, for the most part, completely oceanic; nearly all of the catch is made well outside the territorial limits of any nation.

The Inter-American Tropical Tuna Commission

Under accepted concepts of freedom of the seas, and free access to the resources thereof, the tunas are truly an international resource, and their scientific investigation and conservation is an international problem. Being cognizant of the need for adequate knowledge of the resource on which the tropical tuna fishery is based, the governments of the United States of America and the Republic of Costa Rica in 1950 entered into a Convention establishing an Inter-American Tropical Tuna Commission having as its objectives gathering and interpretation of factual information to facilitate maintaining the populations of yellowfin and skipjack tunas, and of other fishes taken by tuna fishing vessels in the Eastern Pacific Ocean, at a level which will permit maximum sustained catches year after year. The Convention provides for the subsequent adherence of any other nations having a mutual interest in these fish populations.

The Commission employed a scientific staff and initiated its investigations in January 1951. Headquarters are maintained at the Scripps Institution of Oceanography, with which the Commission's staff works in close co-operation. A regional office at Puntarenas, Costa Rica, has also been established for the study of the biology and ecology of bait fishes.

The scientists of the Commission have a unique opportunity to study the dynamics of an important commercial fishery during the period of its growth and development. Fortunately, suitable statistical and other records have been maintained to measure the changes in catch and abundance of the tunas during the period of greatest growth and development of the fishery from 1931 to the present time. This is an unusual and most fortunate situation. Most often in the past, little interest has been evinced in the investigation of commercial marine fisheries, particularly those of an international character, until the fishery has become so intense that economic distress of the industry has demanded remedial measures. This has most often been so long after the period of underfishing that suitable biological statistics for the

period of early development of the fishery are fragmentary or unobtainable. In the case of the tropical tunas, we have, then, a unique opportunity for the study of the dynamics of a large, oceanic fishery, the results of which will be of far-reaching value not only to the welfare of the tuna fisheries, but to the knowledge of the dynamics of commercial fisheries in general.

The investigations of the Commission have, so far, centered on the compilation and analysis of the records of the fishery in order to derive quantitative measurements of changes in the fish population in response to changes in intensity of fishing and catch, both currently and historically. For the adequate interpretation of such data, there is, of course, required considerable knowledge of the life histories and biology of the species concerned, and a fair start has been made on obtaining this. Knowledge of the relation of the behavior of the tunas to the spatial and temporal changes in the oceanic environment is also essential to understanding of their population dynamics. Investigation of these matters is a costly line of research, requiring work at sea with large, expensive vessels. The budget of the Commission has been inadequate as yet to do as much in this direction as is desired, but, with the assistance of the Scripps Institution of Oceanography, the California State Fisheries Laboratory, and the U. S. Fish and Wildlife Service, a good deal of work in this direction has been gotten underway.

Most of the investigations of the Commission are yet unready for announcement of results. Intermediate studies along some lines of research are, however, nearing completion and will be published in the near future. Scientific contributions of the Commission will be published in a series of Bulletins. Staff members also publish minor papers in standard journals. Annual progress of investigations is reported on to the member governments and to the public by means of publication of a series of Annual Reports.

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FIG. 1.—Catch of yellowfin and skipjack tunas from the Eastern Tropical Pacific, 1918-1952.

RECENT STUDIES ON TUNAS AND MARLINS IN JAPAN

By Hiroshi Nakamura [1] and Yoshio Hiyama [2]

Because the tunas and marlins fisheries are important in this country, numerous works have been produced by our biologists over a long period of time, but here we shall describe some recent achievement of our biologists as regards these fishes.

(1) Taxonomy

Only a few amendments and additions have been made since Kishinouye (1923) reviewed the fishes of Thunnidae. Jordan and Evermann (1926) established gen. *Kishinoella* for *Neothunnus rarus* Kishinouye and added *Neothunnus itosibi*. Nakamura (1939) thought the latter had no difference from *N. macropterus*, and Serventy (1941) thought the former was a synonym of *K. tonggol*. Kamohara (1940) changed the name of the Japanese bluefin tuna to *Thunnus thunnus* Linn. and that of the albacore to *G. alalunga*.

About Xiphiiformes, since Nakamura (1937) reviewed Istiophoridae and Xiphiidae of the West part of the Pacific, Hirasaka and Nakamura (1947) made a few amendments and additions. They established gen. *Kajikia* for *Makaira mitsukurii* Jordan & Snyder, added *K. formosana* and established gen. *Marlina* for *Makaira marlina* Jordan & Hill, and added *Eumakaira nigra* N.g. n.sp.

(2) Distribution and Migration

As most of the fishes are caught by the long line in this country, the method of tagging is quite difficult though so many efforts have been made. Now the tagging method for the pole and line fishing is under investigation with the cooperation of both authors.

Therefore, our knowledge on the migration of these fishes is merely based on the seasonal change of the fishing grounds, about which so many data have piled up already. On the other hand, since Kishinouye (1923), so many biologists like Kimura (1941–1949), Uda (1935–52), and Aikawa (1933) have discussed the oceanographic conditions of the habitation of these stenothermal fish species from various points of view. Recently Nakamura worked out the distribution of these fish kinds by

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the recent twenty-year records of Japanese Tuna fleet activities. His work was done mainly to see geographical distribution as regards the density of fish in fishing grounds throughout the seasons. To measure the density of fish, he used the number of certain species of fish caught by one hundred hooks in a long line by the records brought by commercial boats, which is a sort of average catch, catch per amount of fishing effort. Many maps showing the density distribution of each fish species for each month of each year and of the average of the past twenty years have been prepared for printing. Here a part of it is introduced as an example.

Thunnus orientalis. Though Kishinouye (1923) thought the southern limit of the distribution would be 30°N, Nakamura (1936, '38, '43, '49, '51) reported the existence of fishing ground from March to June in the Northeastern part of the South China Sea, North from 15°N in the East of Luzon, and near Formosa and the Ryukyu Islands. Nakamura also thought that the fish in the East of Luzon would be independent from the fish that appear near Tanegashima (130°E, 30°N) from March to December, judging from their size composition and sexual maturity. Beside these, Shimada (1951) reported the occurrence of this species in the equatorial area from June to September, and Jordan & Evermann (1926) reported its occurrence in Hawaii and in the U.S. Pacific coast. The northern limit reported by Isahaya (1935) is near 50°N in Karafuto. The amount of catch of this species by the Japanese fleet was near to nothing in 1940, but has been much better since 1950.

Germo germo. Uda and Tokunaga (1937) thought the fish caught by the Japanese fleet can be divided into three groups: a small-sized group in coastal waters off Honshu, a medium-sized group in the grounds further off shore, and a large-sized group found further East from the former. Each of the three groups migrates clockwise, and intermingle at the point near 155°E, 40°N, having its southern limit in subtropical convergence. From the data Nakamura compiled, he thought that although it is evident that the bigger size of fish is found in the more eastern grounds, it is hard to separate the group as the change is so continuous, and it might be caused by the economical size selection of fishing by the commercial boats. The fishing ground usually goes South during the fishing season at a speed of 2–6 miles per day, and in March it arrives at the Southern extremity, that is, subtropical convergence, and it goes back to somewhat North in April. The size of the fish in the front line of this southward migration is usually bigger than that at the tail, which is found somewhere North from the former. South from the subtropical convergence to the equator, a large-sized group is found,

though the density is thin. This is supposed to be the spawning group which came from the North, but this is not confirmed by accurate evidence. One somewhat distinct group of large-sized fish usually goes southwestward from October to February in a thick density, at 135°E, 12–25°N; but the relation with other groups is still not clear.

Parathunnus mebachi. The previous works on the migration of this fish discuss mainly the oceanographic conditions of the fishing grounds, but Nakamura, by his density distribution maps, found the following facts. The two separate fishing grounds exist in this area. The one at about 40°N in the Northwest Pacific in September is stretched along the latitude line to the date line eastward, and then goes down South, like *G. germo*; but the speed is slower than that, so this fishing ground is always located at the North of the front of that. Another group of fishing grounds exists all year round at 8 to 12°N, a contact line of equatorial countercurrent and North equatorial current. These are not homogeneously stretched as a line, but form some isolated groups within them. He still has no definite idea on the relationship between the two. Besides these, a fishing ground appears in 20–25°N during a certain season. The relationship of this to others is unknown. Kamimura (not printed) recognized the phenomenon that the modes in size-frequency curve differ every other year in the Northwest Pacific.

Neothunnus macropterus. Past works are concerned mainly with the oceanographic conditions of habitation, especially the temperature of the water. However, Nakamura by his density distribution maps observed the following facts. The size of fish is generally smaller in the coastal area of Japan and gets larger in the grounds offshore to the East. A remarkable change of size composition is also recognized according to latitude in the same longitude in the same season, and the border lines of this change are at 3–4°N and 7–8°N, which, he thinks, are caused by the influence of the South equatorial current, the equatorial countercurrent, and the North equatorial current. Also, he thinks that the different fish groups would come in and out by the influence of the monsoon in the seas which are surrounded by land or islands such as South China Sea, the Sulu Sea, the Celebes Sea, the Banda Sea and others. The same fact would be supposed to exist at the coastal waters off Timor, the Small Sundas and other equatorial areas in the Pacific. Before Nakamura's work it was believed that most condensed grounds are in the equatorial countercurrent, but he thinks it would be somewhere South from the contacting area of the equatorial countercurrent and the South equatorial current.

Hiyama wants to add, seeing Nakamura's distribution maps, that this species has less tendency of southward migration shown in the foregoing two species, and that the thick distribution is found in the area more influenced by the coast, or by the existence of islands or lands. Hiyama and colleagues are now working on the morphometry of the above-mentioned four species after the method used by U.S. biologists, but it is still too early to report the results.

Neothunnus rarus. As the catch by the Japanese fleet is not enough to indicate the distribution and migration, the only fact that Nakamura can see is that this species is distributed in the area near the Indo-Australian Archipelago, with its northern limit at the Ryukyu Islands.

Istiophoridae. Tetrapturus angustirostris has remarkable oceanic character in general and is thinly distributed in the tropical and subtropical area. A thick fishing ground appears usually off the east coast of Formosa from November to January.

Istiophorus orientalis has wide distribution in the West Pacific, having a rather coastal character. The center of the distribution is thought to be in the Indo-Australian Archipelago, and its northern limit is in the North polar front. From May to August a thick fishing ground appears near the Philippines and Formosa. *Kajikia mitsukurii* has more oceanic character than the former, and has also a wide distribution extending to the North Pacific, with its center at subtropical convergence. The dense fishing grounds appear at 30–40°N in autumn, and moves south in October. And from March to June the dense group of the grounds appears in 20–30°N. After *K. mitsukurii* went down south, fishing grounds in 30–40°N are occupied by *Xiphias gladius.* The distribution of *K. formosana* is not yet well known. *Eumakaira nigra* has a remarkable oceanic character, distributed in tropical and subtropical area. This species has its distribution range south of that of *K. mitsukurii.* This shows a northward migration from May to July, with its northern limit at subtropical convergence, and reaches to 20–26°N zone nearly one month later than *K. mitsukurii.* The female of this species is always bigger than the male. The latter rarely exceeds 100 kgm. in weight, so the size composition of the catch should be considered based upon the sex ratio of it. *Marlina marlina* is confined within the coastal area of the Indo-Australian Archipelago, as already indicated. This also has a size difference between the sexes, the male rarely exceeding 120 kgm. *Xiphias gladius* is thought to have world-wide distribution, but in the Northwest Pacific the dense distribution is recognized by Nakamura at the North from subtropical convergence beyond 43°N. In August a good fishing ground is usually formed in 150–155°E, 40–43°N, which moves south thereafter, just like *Germo*

germo, down to the east of Bonin Island in March, and fades away. Nakamura and others (1951) think that the spawning ground of this fish would be in the South from subtropical convergence, because they found so many juveniles of this in this area.

(3) Spawning Habit

In general, Nakamura thinks these oceanic fishes have a long spawning season, sometimes almost all year round, and have their spawning grounds widely distributed throughout tropical and subtropical, and sometimes even in temperate zones in the Pacific, based upon the recent data of collection of eggs and juveniles of these fish kinds, done intensively by Japanese research vessels. Regarding the spawning grounds of *Katsuwonus pelamis*, many biologists, such as Schaefer & Marr (1948), Shimada (1951), and Wade (1950, 1951) reported juveniles from various parts in the Pacific. Yabe (unpublished) got ten individuals of 5 to 10 mm. long juveniles of this species from the collection of our research vessels during 1947 to 1952 from near Ryukyu, off Honshu and in Micronesia in April to September. Suda (unpublished) found large numbers of juveniles from stomach contents of tunas and marlins caught from various parts of the Pacific, and found evidence that the smaller (5 to 20 mm. long) juveniles are obtained from the area south from subtropical convergence, and the larger ones (over 20 mm. long) were found in the area to the north. About *Thunnus orientalis*, Kishinouye (1923) thought that this would spawn in June and July in the area off Honshu, but later Kawana (1935) reported its spawning in the Japan Sea, and Nakamura (1938, 1939) found the ripened ovarium in the fish caught near the Philippines from the middle of April through the middle of May. About *Germo germo*, Watanabe (1939) reported that he obtained the ripened ovarium in the fish caught near Midway Island, and Schaefer (1948) and Brock (1943) got some idea on this matter. The data obtained by Japanese research boats are now under investigation. About *Parathunnus mebachi*, Shimada (1951) found ripened ova in the fish caught from the area 143–160°E, 1–10°N from June to September, and thought that the spawning season might continue later than this period. Recently biologists on board the research boat of Nankai Regional Fisheries Laboratory succeeded in the artificial fertilization of this fish in the equatorial region. About *N. macropterus*, Nakamura (1939, '43, '49, '51) reported that he found ripened ova in the fishes caught in the South China Sea from March to May. Wade (1950) thought the season near the Philippines was from May to August, and afterwards he obtained the juveniles (9.4–37.5 mm. long) and could assure both the locality and the season. Shimada

(1951) found spent fishes in the area 150–200 miles northwest off Kapingamarangi Island at the beginning of August. Schaefer (1948) and Schaefer & Marr (1948) found juveniles in Central America from January to May. About *N. rarus* we have nothing to add to Delsman & Hardenberg (1934) and Serventy (1942).

About *Tetrapterus angustirostris,* Nakamura (1937, '38) found ripened ova in the fish caught east of Formosa and thought this would spawn in November and December in this area. About *Istiophorus orientalis,* Nakamura (1932) reported in December the ripened ovarium in the fish caught from Molucca Strait. And later he (1938, '42, '43) also found ripened ova and juveniles and witnessed the spawning behaviour near Hainan Island, near Formosa and east of Luzon Island from April to September. Near Japan so many juveniles were found since Uchida (1937). Also, recently Nakamura and his staff obtained so many juveniles from tropical areas such as Micronesia from June to September. However, they have some difficulty identifying these as this species, because the difference from *E. nigra* is not assured in juveniles yet, and the latter species matures and grows abundant in the area in this season. About *Kajikia mitsukurii,* Nakamura found ripened ovarium as usual from April to May near Formosa, and thought that this also spawns in the same season around Bonin Island. Recently Nakamura and his staff found ripened ovaria in the fishes caught from the equatorial area from June to September. About *Eumakaira nigra,* Nakamura (1938, '42, '49) found ripened ovaria of fish caught east of Luzon Island, and thought this would spawn from April to August near Luzon and Formosa. Recently he and his staff found another spawning ground near Bonin Island in the same season, and in the equatorial area of the Pacific they also found grown-up fishes from June to October. About the above-mentioned four species Nakamura (1944) found the seasonal change of both size composition and sex ratio, which changes remarkably after the spawning season. The juveniles of *Xiphias gladius* in the Atlantic Ocean have been reported already. About that in the Pacific, Yabe (1951), Nakamura and others (1951) reported 11–35 mm.-long young, and there were plenty of larger young found in the stomach contents of tunas and marlins.

(4) Age and Growth

The age determination of these groups of fishes has been made by counting the number of rings in the centrum of the vertebrae. Aikawa (1937) reported the growth of *K. pelamis* by this method and size composition of the catch. Afterwards Aikawa and Kato (1938) worked on the growth of *G. germo, N. macropterus* and *T. orientalis* by the

same method. Ban (1941), Higashi (1941), Ikebe (1939, '40, '41) reported the growth of *K. pelamis, N. macropterus, P. mebachi, G. germo* by the method of size composition of the catch. Kimura (1932, '35) worked on the same problem about *T. orientalis* and *N. macropterus,* by the seasonal change of size of catch in the Izu Region. Recently Moore (1951) reported that of *N. macropterus* near Hawaii. The growth rates obtained by these workers have big differences from each other. For example, about that of *N. macropterus* a big difference exists between Aikawa & Kato, Kimura and Moore. To examine the numerous samples to get the accurate age composition of population, instead of size composition, the centrum reading method is inconvenient. So now the scale reading method is going to be established by Hiyama, as the scale samples can be collected easily from numerous specimens before the fish is dissected. It is already affirmed by him that the ring in the scale is formed once a year during a certain long season. It will be published in the near future, and now the age determination by this method is going on to get the age composition of the catch.

(5) Feeding Habit

Many reports have already been published on the stomach contents of these fishes, but many of them are fragmental and not enough to see the relationship between foods and migration. Nakamura (1936) noticed the difference of the stomach content of *N. macropterus* in the Celebes Sea between the fish caught during the Northeast wind season and that caught during the Southwest wind season, and by this he guessed the seasonal change of the fauna in this region. Suyehiro (1936) reported the stomach contents of *K. pelamis* and he also (1938) reported that of *N. macropterus, P. sibi,* and *T. orientalis.* A group of biologists with us are now working systematically on the stomach contents of these fishes, but the results are not ready for publication. In general, these carnivorous oceanic fishes have less tendency to be selective as to food, as so many various fishes may be found in their stomachs, sometimes including the garbage of vegetables thrown out from boats. Marlins are generally taking larger fish having greater swimming power than tunas. And the latter, though variation according to species is shown, generally has a tendency of a plankton feeder in any degree, and it is most conspicuous at *G. germo.* With reference to fishing, the reason why some school of tunas would not take the bait was investigated by Suyehiro (1938) and others.

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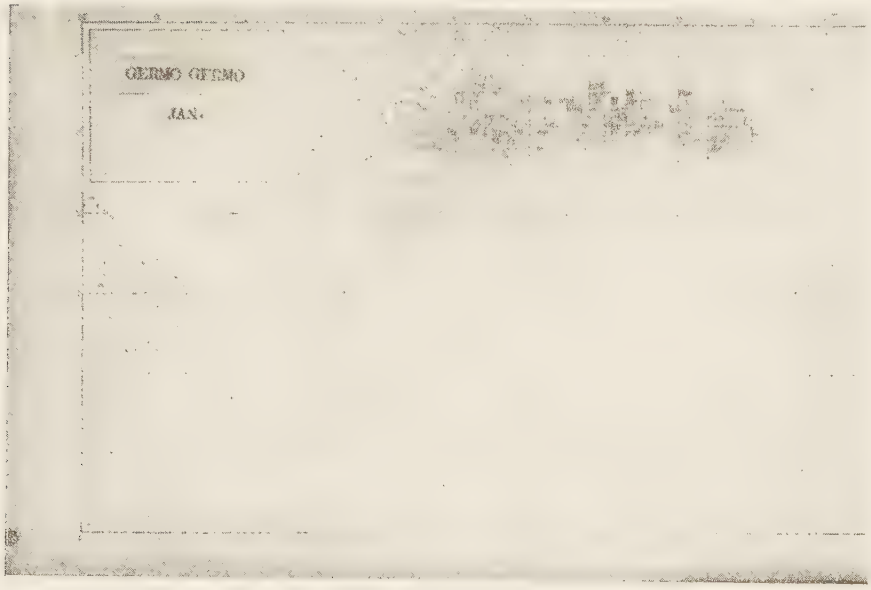
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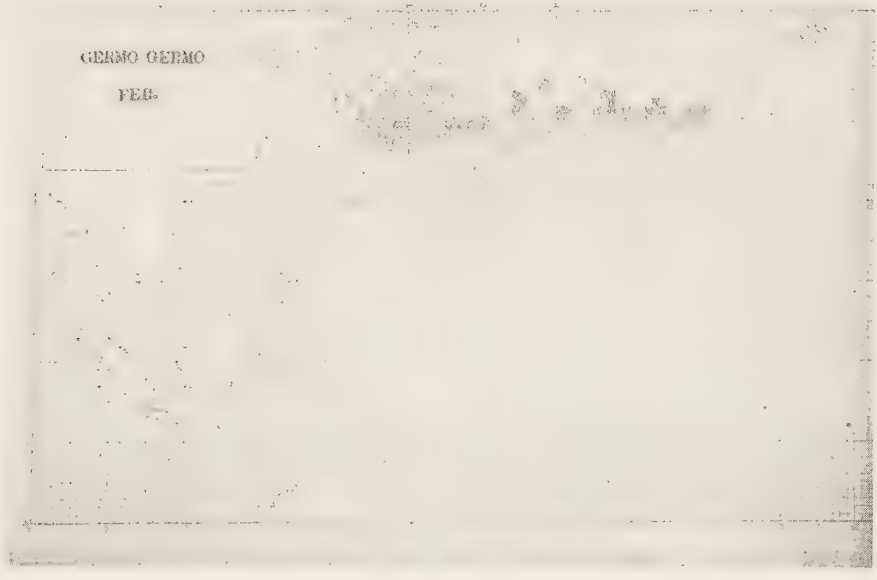
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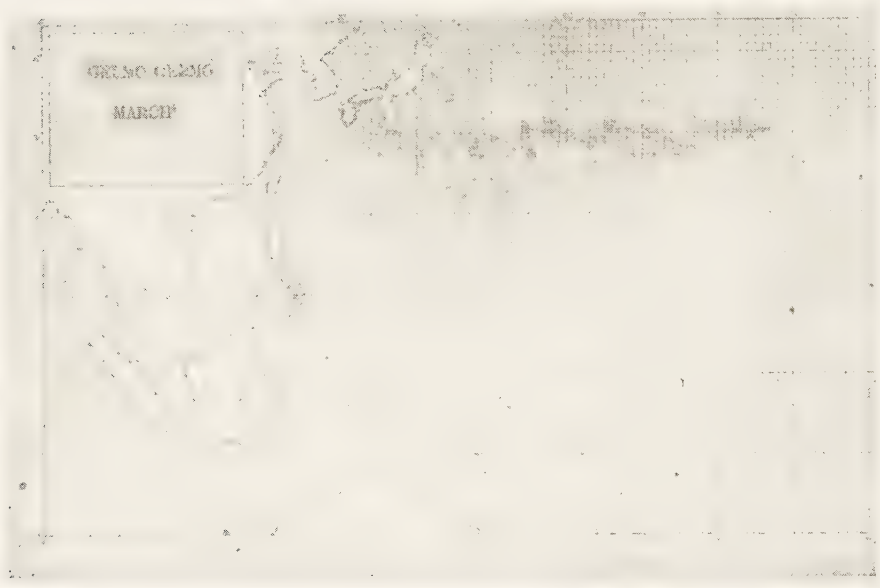

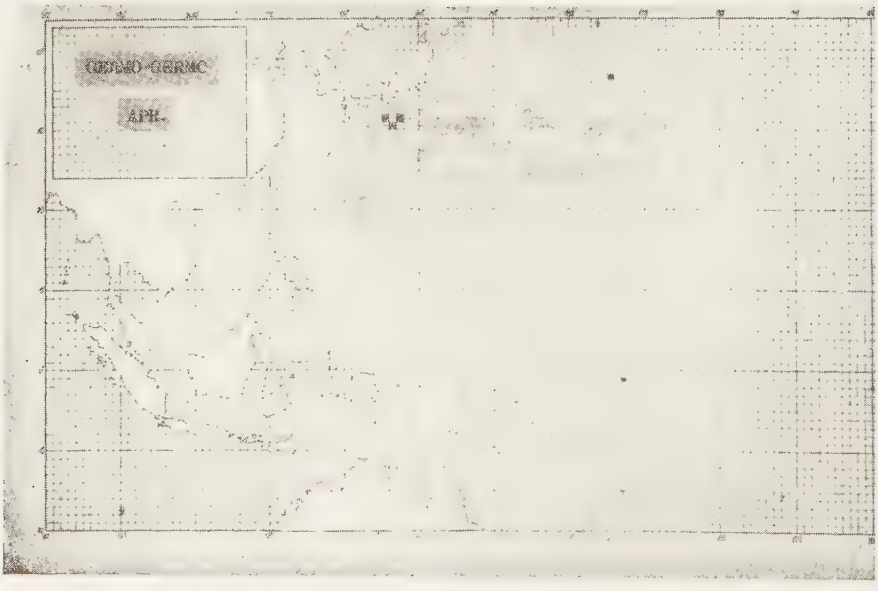

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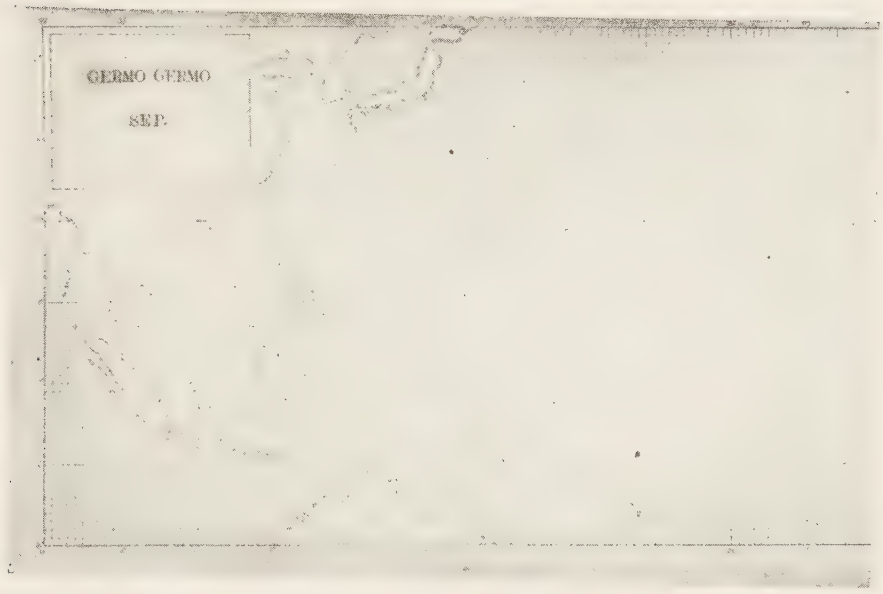
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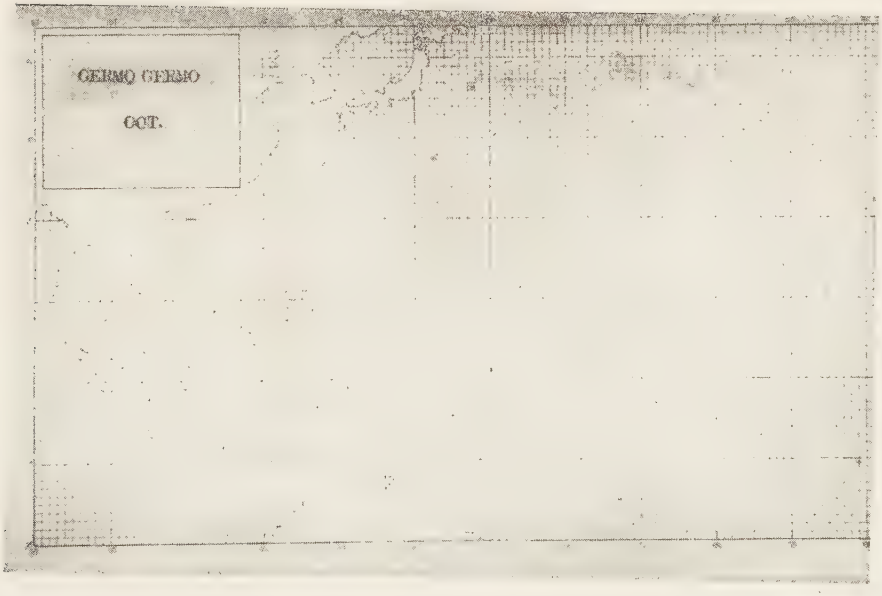
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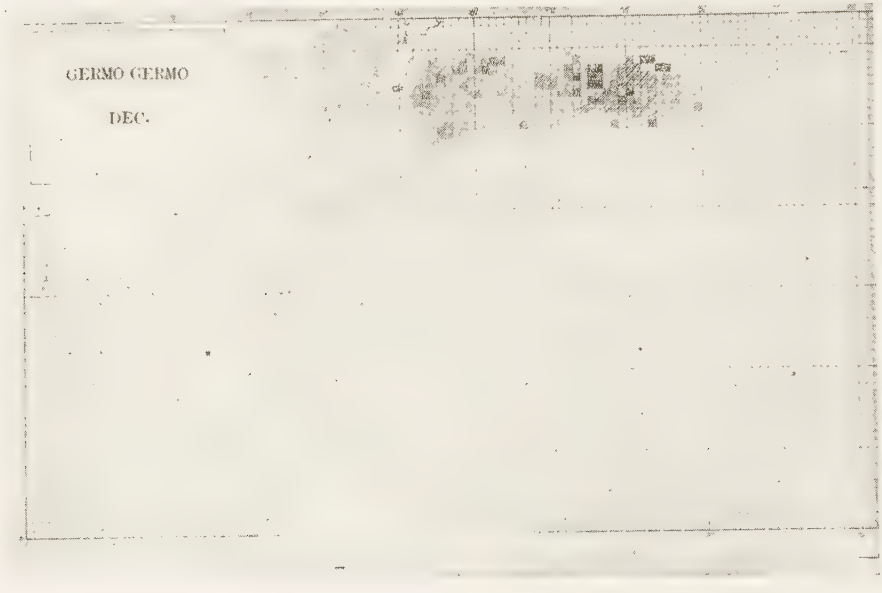
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ARE THE WORLD-WIDE DECLINES IN SARDINE CATCHES RELATED?*

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Large fluctuations in the catches of marine fishes, especially pelagic species, have long been known and may, in a sense, be considered to have given the original and major impetus to the birth and growth of the science of fishery biology. Indeed, such fluctuations have been observed to occur in so many different species and areas that one might suppose them to be a characteristic feature of the great fisheries. It is significant, however, that fishery biologists are not in general agreement as to the causes of these fluctuations.

Recently there have been major declines in the catches of some of the sardines; declines which have caused great economic hardship and have, at least in one instance, resulted in a greatly expanded research effort (Anonymous, 1950). We refer especially to the Japanese landings of *Sardinops melanosticta,* the North American landings of *S. caerulea,* and the Portuguese landings of *Sardina pilchardus.* These landings are shown in Figure 1.

The North American data include landings in Canada and the United States. Relatively small landings made in Mexico are also included since 1940. It has been demonstrated (Schaefer, Sette and Marr, 1951) that from the inception of the fishery until 1942, the growth of the fishery, as shown by the annual catches, followed a logistic curve characteristic of the growth of many industries. Some of the deviations about the curve are clearly related to economic conditions; the economic depression of the early 1930's, for example, is reflected in the reduced catches during that period. From 1934 until 1944 the annual catch fluctuated around an average of about 550,000 metric tons. Following 1944 the catches have declined, in some seasons catastrophically so, but with a short-lived partial recovery in 1949 and 1950. The basic causes of this decline have not been completely elucidated, but the major immediate causes include a series of smaller than average year-classes and a probable shift in the distribution or migratory behavior of the fish; the relation of an intensive fishery to these factors has not

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been determined to the satisfaction of all concerned (California Marine Research Committee, in press).

The Japanese data include only the landings made in the Japanese islands; they do not include landings in continental Asia. In some years the latter were as large or larger than the Japanese landings. In addition, it is not certain that the data include all Japanese landings, nor that they refer entirely to the sardine. Nevertheless, and on a bigger scale, the curve of annual catches in the Japanese fishery is remarkably similar to that of the North American fishery. The peak catch was obtained in the same year, but the decline started about two years earlier. In 1951 there was a partial recovery.

The Portuguese data include only the landings made in Portugal. Obviously this fishery has never attained the magnitude of the other two. Properly, this curve should include the catches of *Sardina pilchardus* landed in all European and North African countries, but these data are not available to us at the moment. The Portuguese landings are therefore used as an example of the northeastern Atlantic sardine catches. There is a peak, although not a pronounced one, in the Portuguese catches occurring at about the same time as in the other two fisheries. There is a decline occurring slightly later than in the North American fishery. We understand that more recent seasons have shown a recovery of the Portuguese fishery, but have thus far been unable to secure exact data.

These same catch data are also shown in Figure 2, but here, for each fishery, the catch in each year has been expressed as a percentage of the largest annual catch made in that fishery during the period reported. This shows the relative fluctuations in the three fisheries without respect to their absolute magnitudes. The similarities already mentioned are even more strikingly shown in this figure, especially the relative magnitudes of the declines in catches and their close relation in time, even though not simultaneous.

It is often inferred that when the catch of a particular species becomes less, the absolute size of the population is also reduced. This is not necessarily true and it should be remembered that the data just presented refer only to catches. The relation of these catches to the size of the populations from which they were drawn is not known.

The reasons for a major decline in catch in any fishery must be found among one or more of the following: (1) a decrease in the amount of fishing effort expended per unit of time; (2) an increase in the rate of natural mortality; (3) a decrease in the rate of recruitment (i.e., a decrease in year-class size); or (4) a decrease in the availability of the fish to the fishery, through a change in behavior or distribution.

For the three sardine fisheries mentioned, we may safely rule out (1) as a cause of the decline in the catches (barring war-caused interruptions in fishing); one or more of the other three must be responsible.

In order to examine the possibility of the other causes being operative, various types of information are needed. In the case of natural mortality rates, some estimates have been made, but they are not very precise. In addition, for sardines, or practically any marine fish for that matter, we have only general ideas about the various sources of natural mortality and practically no ideas about how they operate. In any case, they are not subject to modification by man, except as fishing mortality may replace natural mortality.

Variations in rate of recruitment are probably one of the two major causes of fluctuations in catch (the other being variations in availability). Here again, we have only general ideas about the natural causes of variation in year-class size and how these causes operate. So far as all present evidence goes, such variations are natural. However, in theory at least, the size of the spawning stock could influence the size of the resulting year-classes. If the theory holds, Man could control year-class size by controlling stock size, but this remains to be demonstrated in practice. Data on relative year-class sizes as they appear in the catches are of record, at least for the North American sardine fishery. What we need, however, are data on year-class sizes as they exist in the population.

Variations in the availability of fish to the fishery are, as indicated, a major cause of fluctuations in catch. Accurate availability data are extremely difficult to obtain and, in general, availability phenomena are among the least understood in the field of fishery biology. For most marine fisheries, however, it is difficult to see how they could be anything but natural and not subject to control by Man.

So, the problem of the causes of these declines falls into two major divisions: (1) What are the effects of Man's activities and how do these operate, and (2) What are the effects of natural phenomena and how do these operate? Solution of these two sets of problems will require not only additional observation, but also the development and testing of theory.

Returning to our original question, if the declines in catches of sardines were caused solely by Man, then the declines are indeed related. Such a relationship is not within the province of the fishery biologist, although the mechanics of its operation obviously must be.

On the other hand, if the declines are natural ones, how could they be related? Such relationship could only be through a pandemic, which has greatly increased the rate of natural mortality and for which, incidentally, there is not much evidence, or, through some rather world-

wide meteorological or oceanographic change. The latter possibility has, in fact, already been suggested by Nair and Chidambaram (1951) and by Uda (1952).

With the data at hand, it is not possible now to answer the question posed by our title. Before the answer is attained, some, at least, of the problems need to be more clearly formulated; data need to be assembled, some of which are published in relatively obscure sources or are not published at all; plans need to be laid and implemented; and, finally, means must be found to promote greater exchange of observations and ideas among fishery biologists and oceanographers who face these common problems. All of these objectives might be best attained through the medium of international conferences.

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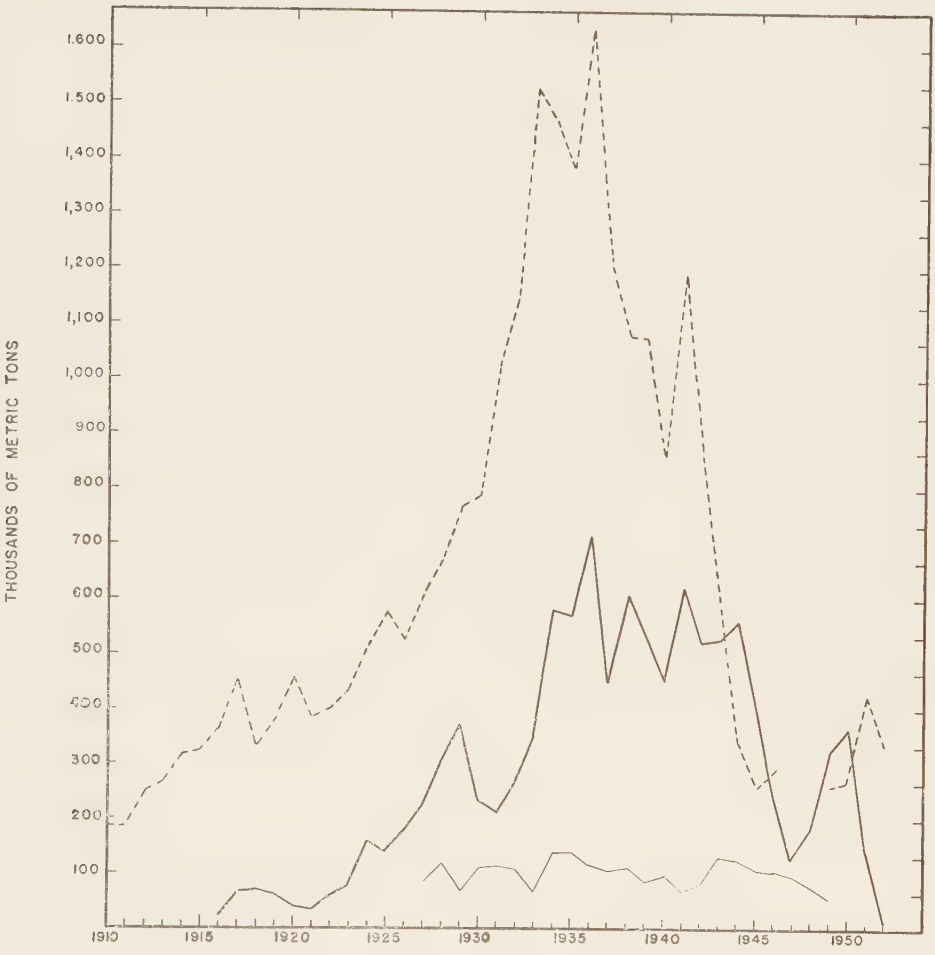

FIG. 1.—Total sardine catches for the United States (———), Japan (- - - - -), and Portugal (———). Data obtained from the following sources: *United States-Calif. Fish and Game*, vol. 34, no. 2, p. 83 (1948) and unpublished information; *Japan-U.S. Fish and Wildlife Service Fishery Leaflet* 279, p. 83 (1948), and from personal communication from Dr. N. Nakai of the Tokai Regional Fish. Res. Lab.; *Portugal-Bull. Stat., Cons. Perm. Intern. l'Explor. Mer*, and unpublished information.

FIG. 2.—Sardine catches of the United States (———), Japan (- - - - -), and Portugal (— — —), expressed for each fishery, as precentages of the highest annual catch taken during the period under consideration.

THE PRODUCTS OF THE SEA AND THEIR EXPLOITATION AND UTILIZATION IN PAKISTAN

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A comprehensive study of the Sea as a store-house of immense mineral, vegetable, and animal wealth is beyond the scope of the present paper. Only those products of the sea which are important from the fisheries point of view and which occur in the waters off the coast of Pakistan will be considered.

The demand for protein food in Pakistan is far in excess of the present supply. Availability of grazing grounds and fodder imposes limitations on the increased production of livestock in the country. Faced with the problem of short protein food supply, Pakistan has turned particular attention to her aquatic protein food resources.

Fish has a pronounced dietetic importance in Pakistan. During 1952 consumption of fish in Pakistan stood at 295.2 million pounds, of which 242.8 million pounds were consumed in East Pakistan. Rice and fish constitute the staple food of the population in East Pakistan and no less than 90% of the people consume fish as a regular item of diet. In West Pakistan consumption of fish is low except along the coast and the riverine tracts. Annual per capita consumption of fish in Pakistan has been estimated at 6.4 pounds. In East Pakistan in certain localities where the supply is plentiful the per annual capita consumption may be quite high.

Economically the importance of fishery to Pakistan is considerable. It is estimated that there are over 200,000 fishermen families in the country and as many as 800,000 subsist by fishing. In East Pakistan alone there are 160,000 fishermen families and over 650,000 make a living out of fishing. These figures include fishermen engaged in fresh water fisheries. Furthermore, the economy of Pakistan is basically agrarian. It is desirable that the country's agriculture be supplemented by a well-organized fisheries industry.

The Resources

Pakistan has a total of 700 miles of coast line, 500 miles in West Pakistan and 200 miles in East Pakistan. The coast of West Pakistan is bounded by 23°–40′N to 25°–30′N latitudes and 61°–40′E to 68°–10′E

longitudes. The coast of East Pakistan lies between 20°–50′N to 22°–50′N latitudes and 89°–00′E to 92°–20′E longitudes. The coast of West Pakistan falls into two distinct divisions: the Mekran coast and the Sind coast. The Mekran coast extends over a length of 350 miles from Hub River, about 20 miles West of Karachi, to Gwatar Bay on the Iranian Border. The coast has a number of bays and is interrupted by two breakwaters. The most important breakwater on this coast known as Miani Hor lies about 60 miles West of Karachi. It is approximately 40 miles long and at places 10 miles broad. There are no perennial rivers on the coast; all the rivers and streams remain dry except for a few days of occasional rain brought in by the southwest monsoons during summer and northeast cyclones during winter. The total rainfall on the coast is less than 3 inches a year. Hills, some of which rise up to 3500 feet, are bleak and barren, and run parallel to the coast sloping steeply into the sea.

The Sind coast extends from Karachi to Sir Creek over a length of 180 miles, and is marked by a network of creeks which extend to a considerable distance inland. These creeks have been formed by the Indus and other rivers as they change course from time to time. Hills are noticeably absent on this coast.

The coast of East Pakistan is broken by the mouths of the Ganges, the Brahmaputra and numerous other rivers. The 200-mile-long coast is plain except for a fringe of hills on the southeast. These hills are a continuation of the northeastern wing of the Himalayan ranges.

Beyond the territorial limits of Pakistan lie the waters of the Bay of Bengal in the east and the waters of the Arabian Sea in the west. The floor of the Bay slopes slowly from the shores and the 100-fathom line lies 100 miles from the coast. The bottom topography is smooth except for a submarine canyon directed southward from the mouth of Pusur river. The ocean bottom is covered with thick layers of terrigenous ooze. The salinity, turbidity and other physical, chemical and biological features of the waters of the Bay are greatly influenced by the heavy discharge of the Ganges, the Brahmaputra and other rivers. The wind movement and revolution of the earth give a rotary movement to the waters of the Bay.

In contrast to the Bay of Bengal, the Arabian Sea is open and its waters are subject to influences of the South-East current, of current movements originating in the Mozambique channel and the rotary movement in the Arabian Sea. These movements undoubtedly influence the physical, chemical and biological properties of waters of the Arabian Sea. The discharge of the Indus also exerts pronounced influence on the character of the water in that part of the Arabian Sea which

lies off the Indus estuary. The continental shelf area of the Arabian Sea is restricted. It is about 100 miles only off the Indus estuary and shrinks to about 30 miles off the Mekran Coast. The edge of the continental shelf lying at the 100-fathom line falls steeply into deep water. A submarine canyon cuts the shelf opposite the Indus estuary. The area adjacent to this is subject to a considerable amount of silting.

Fauna: The fauna and flora of these waters are fairly known from a systematic point of view. Schools of '*Sciaena, Tuna, Polynemus* and *Pristipoma*' have been observed to be present in seasonal pattern on the surface of the off-shore waters. In mid-waters 'Cybium and Elasmobranchs' are present, whilst the fauna of the bottom waters comprise '*Synaptura, Cynoglossus, Lutianus,* and Elasmobranchs'. The inshore fauna which are endemic and which share some elements of the off-shore, brackish, and fresh-water fauna, consist of stocks of '*Mugil, Sillago, Chrysophrys, Gerres* and *Lutianus*' in addition to a very substantial fauna of '*Penaeidae.*' The brackish water areas which are extensive, totalling about 7,500 square miles, include a vast network of waterways which are inhabited by a varied fauna of '*Mullets, Perches, Herrings*' and an extensive stock of oysters. The brackish water conditions which penetrate the main river course influence to a great extent the up-stream ascent of the very important fish Hilsa or Palla—'*Hilsa ilisha*'.

Beyond the faunistic lists, knowledge of the resources is seriously limited. Whilst the general distribution of a few of the more important species is known, the precise distribution of these, and the variation of the limits of distribution from season to season, is not known. Little information is available on the life history in terms of spawning seasons and habits, feeding habits, and migratory movements of these species. There is no record of any estimate having been attempted, of the natural abundance of any species of the area. Certain species are known to be more abundant than others; at least, greater catches are taken by the fishermen. But whether these catches approach or exceed the proper limits which the natural stocks can sustain, is not known.

The Industry

The primary phase of the fishing industry consists of the following major divisions:

(1) Capture operations in the off-shore waters,
(2) Capture operations in the brackish waters and open waterways of the Gangetic and Indus delta and
(3) Culture operations in the estuarine areas.

Culture operations in East Pakistan chiefly take place in the estuarine areas. The operations which concentrate on mullets, perches and prawns are simple and involve basically the construction and maintenance of bunds, the control of water movement and, where necessary, some feeding. It is estimated that over 20,000 persons are engaged in these culture operations.

Fishing by capture operations is carried out in surface, middle, and bottom waters. These operations at present are confined at 8–10 miles from the shore and the 10-fathom line. While these operations are thus confined they are also restricted in their along-shore extent. The fishermen do not carry any navigational equipments nor do they have any knowledge of the science of navigation. It is impossible for them to go beyond the visibility of the shore.

Fishing Season: During the months of June to August the southwest monsoons are in full swing and there are heavy swells in the sea making it impossible for any fishing operations to be conducted in the open sea. Limited fishing is carried out in the protected waters of the estuarine areas. Throughout the rest of the year fishing is conducted with varying degrees of intensity in all waters.

Fishermen: The number of fishermen engaged in marine fishing in Pakistan has been estimated at 85,000. In addition to active fishermen there are those concerned in handling and transport, processing and preservation, the middlemen and merchants, and market operatives.

The fishermen live in important port towns and in isolated villages along the coast. During seasons for particular fisheries, temporary colonies may also be set up. The villages are built on the sandy and unprotected beaches; the huts and tenements are made of mangrove and bamboo sticks, and weed mats.

Fishing is essentially a whole-time occupation for the majority of the fishing group. During the monsoons when no fishing can be conducted in the disturbed sea, the fishermen engage themselves in making and mending nets and repairing boats and fishing in protected waters.

The fishermen are generally illiterate and unskilled. Their knowledge of the behaviour of fish, of the weather, currents, bottom and of the operation of crafts and gears is seriously limited. They are also very much impoverished; their annual money income is probably, on the average, 400–500 rupees (125–150 U.S. dollars) per head.

Crafts and Gears: The crafts are plank-built, wind-driven vessels ranging from 15–60 feet in length and ½ to 50 tons in capacity. They are not decked in and provide no living accommodation even in the larger crafts. The storage of fish is provided merely by wooden boxes and holds without any ice or refrigeration. Smaller crafts carry crew

of three to four and operate on single day journeys. Larger crafts carry from eight to ten persons and stay at sea for four to five days. Sometimes larger vessels stay away from ports for longer periods. In such cases the catch is salted on board and the vessels move every third or fourth day to convenient spots on the shore for drying the salted fish.

In addition to the local operations with country crafts, the Government's experimental trawler 'ALA' has been operating in the waters off the coast of West Pakistan. 'ALA' is 80 feet long and has a gross tonnage of 81.24. She has a steel hull, and a Ruston diesel engine of 150 B.H.P. The fish hold is refrigerated and has a capacity of 30 tons. The trawler employs a Peter Carey trawl, 75 feet long. The operations of the trawler has not extended beyond the 30-fathom line.

The Trawler has made a number of trips. The results so far have not been encouraging. Although the tropical waters are known not to be rich in bottom fauna, the possibilities of trawling in these waters cannot be ascertained until after exhaustive surveys. The operations of 'ALA' are limited both in seasonal and geographical co-ordinates for the purpose of any conclusions.

The gears commonly employed in Pakistan are (1) fixed or stake nets, (2) boat seines, (3) beach seines, (4) drift and gill nets, (5) cast nets, (6) traps and weirs, and (7) hooks and lines. Non-searching type of a gear, e.g. stake nets, drift and gill nets, are numerically predominant and their total catch is more than that of the searching gear. Of the latter group, the boat seines are most important. These nets catch sardines, herrings, drums, croakers and threadfins, depending on size and mesh.

The nets are prepared by hand, using mostly cotton, occasionally hemp, and nylon whenever it is available. Net preservation practices consist of their treatment with lime and occasionally with extracts of some indigenous barks.

The crafts and gears are not mechanized. This severely restricts the fishing operations in their range along seasonal and geographical co-ordinates.

Capital: A reliable estimate of capital invested in the primary industry is not available yet. Preliminary figures place it anywhere from 10–12 million rupees (3–4 million U.S. dollars). Of this nearly 55 percent is invested in crafts and the rest is invested in gears and as recurring expenditure. Capital in Pakistan is noted for its shyness; on the other hand, the manipulations of the middlemen place impediments to the flow of fresh capital in the fisheries industry.

Economics and organisation: The number of owner-operators who work alone as single units is negligible. Some outfits are operated by

the crew; the owner of the outfit generally has a share in the operations, even if only their supervision. The people who operate the gear do so on a share basis. As is usual elsewhere, the boat and gear used in share fishing, count equally with the operatives in drawing a share. In some cases of sharing of earnings the owner makes advances to the crew and undertakes some responsibility for food, either providing it against shares, or guaranteeing the necessary credit. Under such circumstances an arrangement is made by which the fish must be sold to the owner or his agent.

Quite frequently the crew are employed on wage basis. Such crew are provided with gear and are completely 'found.' In East Pakistan the owners of boats and gears engage their agents to assemble parties, of up to 200 or more, of fishermen, curers and others; the workers of the party are engaged on wage basis whilst the agents are contracted to take the catch to the owners, of boats and gears, to sell on an agreed basis. The owners supply food and advance money.

Amount of Production: Annual production is estimated to be in the order of 100,000 tons, wet landed weight of fish. The bulk of this is landed in East Pakistan. Wide variations in the catch exist in different localities, seasons, and in species. Variations of this kind are characteristic of the fishery and have considerable effects on it in every way.

The catch in East Pakistan is composed of 30% Clupeoids, 25% Crustaceans, 15% Bombay ducks and Hairtails, 7% Elasmobranchs, and 11% miscellaneous fish. In West Pakistan the catch consists of 25.5% of Elasmobranchs, 18.5% Perches, 18.0% Crustaceans, 11.5% Mackerels, 10.5% Clupeoids, and 16% miscellaneous fish. In addition there are 3–5 thousand dozens of oysters and clams produced each year.

In the absence of any reliable data regarding production by units of time, of area, the number of crafts and gear, the number of men who fish, it is not possible to measure accurately the total amount of effort and catch per unit effort.

Secondary Industry

The secondary phase of the industry leaves much to be desired. The equipment for handling, transport, marketing and distribution are inadequate and inefficient, this being especially true of ice-making equipment. Processing methods are also not satisfactory and yield products of inferior quality.

Estimates of production passing through various channels of disposal are extremely variable. It is held that of the total production in West Pakistan approximately one third is handled and consumed fresh

and two thirds processed. In East Pakistan roughly 80 per cent is consumed fresh. The products of processing are cured fish, cured prawns, fish fertilizer, fish meal, shark fins, isinglass and liver oil.

Handling and Transport: Of the fresh fish the greater proportion is handled with primitive apparatus and without any means of preservation. The catch generally must suffer the exigencies of inefficient transport, careless handling and inadequate use of ice.

Transport facilities are varied and primitive. Use is made of headloads, bicycles, animal carts and some motor transport. Some use is also made of water transport. In estuarine areas salt is used if the fish is to travel more than 50 miles. The fish rarely arrives at the market and less often reaches the consumer in good condition.

Processing: Fish is commonly processed by (1) sun-drying, (2) salting, (3) salting and sun-drying, and (4) smoking. Salting and subsequent sun-drying is most extensively used in West Pakistan whilst in East Pakistan sun-drying and wet-salting are equally important. Smoking, which is of minor importance, is employed only in East Pakistan. Fertilizers are produced by sun-drying the fish or fish offals and subsequently crushing them. Shark livers are heated in pans by direct fire except in the case of a small quantity of medicinal liver oil produced in East Pakistan by the Provincial Directorate of Fisheries.

The curing yards are inefficient. They provide no elevated platform for dressing fish and most of all, supply of running water in these curing yards is totally absent. Brining tanks where available are built-in and cannot be drained out.

Fish are dried on bare ground or on woven mats. Wooden racks are uncommon.

The smoking kiln is an open pit where local wood or sawdust is allowed to smoulder. No care is taken in the choice of wood or in regulating the rate of burning.

Salt employed for curing is mixed with sand and mud and contains high amounts of sulphates, calcium, and magnesium.

The finished product is generally of poor quality. Unsatisfactory colour and texture, off-flavour and signs of rancidity are noticeable in the cured fish. Considerable damage is caused to the product during storage as the product is left under inadequate and unsatisfactory storage conditions for long periods.

Marketing and Distribution: Fish supplies are accumulated at various collection centres. These centres do not have established market places, nor are they hygienic or efficient in any sense of these words; many of the operations take place on bare ground. In general, the 'fish market' consists of little more than some space and perhaps a few benches allotted in the general market for the selling of fish. In Karachi,

however, a cement floored building is used as a wholesale market. This building does not have sufficient space for handling the total landing nor is it supplied with running water.

The fisherman delivers his catch at the point of landing to an agent who may auction it on his behalf to wholesalers, retailers and fish curers or may buy it from the fishermen where financial arrangement exists between the agent and fishermen. The wholesalers in turn sell the fish to the retailers who sell it to the consumers. The fish curers mainly export their products. The agent who first receives the fish from the fishermen is the individual who provides finance to the fishermen. Apart from the collection of sales tax under certain circumstances the Government takes no part whatsoever in this marketing process at any stage.

Trade: Although there is an overall deficit in the country, in restricted areas there is a surplus in fish supply which is particularly due to inadequate facilities of handling and transport. Pakistan exports some of this localised surplus. During 1952 over 10,000 tons of fresh fish were exported to India. The main bulk of it consisted of freshwater fish and came from East Pakistan. The total export of processed fish stood at 9,635 tons. In addition, during the same year Pakistan exported over 2,000 tons of fish fertilizers, 160 tons of shark fins and fish maws. As against the export, 460 tons of processed fish, 520 tons of fish oils and 173,500 pounds of vitaminous fish oils are shown as having been imported during 1952. The total value of the export trade during 1952 stood at 12,300,000 rupees (3.2 million U.S. dollars) whilst that of the import trade during the same year stood at 1,527,000 rupees (500,000 U.S. dollars).

Socio-Economics: The economic problems of fishermen in Pakistan concern his methods of production, purchase of domestic and production requirements, provision of credit, and the sale of his produce. The craft and gear and other equipment which the fisherman uses are primitive, inefficient and wasteful though effective in their own way. The middlemen to whom, in many cases, the catch is sold in advance, generally, supply the fishermen with his domestic and production requirements, and with other credit accommodation that he may need. He is compelled more often than not by circumstances of trade to buy dear and sell cheap and thus the fisherman sinks irretrievably into debts. Belonging to an economically and socially backward community, ignorant and uneducated, he has generally neither the will nor the means of organising himself for self-emancipation.

Although the fishermen are impoverished and illiterate, these deficiencies of wealth and education may not be presumed to apply to

their technical qualifications. The Pakistani fishermen are competent, skilled sailors, proficient in the use of their traditional equipment. There seems to be no reason to doubt that these men at least will be capable of learning the use of new equipment and the operation of new craft.

The fishermen are unable to attempt on their own behalf development of their equipment and operations. This situation may be attributed to the combined effects of the improvidence of the fishermen, the inefficiency of the equipments, and the manipulation of the middlemen. Certain external influences, such as the demand for fish and the purchasing power of the consuming public, also have a bearing on the situation. There exist considerable differences of taste among people in different parts of the country; coupled with this is the inadequate marketing system, which would seem to make the demand for fish uncertain and weak.

Conclusions and Recommendations

The status of fisheries in Pakistan is low. The resources are capable of yielding a much greater supply of fish than they do at present. The procurement of that increase will require in some cases the introduction of new methods and in others an intensification and improvement of existing methods. Such changes in methods imply comparable changes in the craft and gear, and in certain cases will require adjustment of fishermen. Undoubtedly these changes will demand substantial reorientation of the secondary phase of the industry in order that it may be capable of handling the increased supply and giving a better quality of service.

Increased production, adequate distribution and disposal of the produce are the chief tasks in the development of Pakistan fisheries. Extension of the fishing grounds, improvement and increased employment of gear, and mechanization of the craft will enhance production. Construction of markets at important fish landing centres, provision of sufficient ice and cold storage, railway refrigerated cars and trucks, and of various processing facilities will ensure proper distribution and disposal of the produce.

Well-organised central and provincial Fisheries Departments are formulating schemes for the development of the fisheries resources of the country. As a member Pakistan has received help in this task from the Food and Agriculture Organisation of the United Nations. A thorough survey of the resources has been undertaken in the waters off the coast of Karachi where already a number of good fishing grounds have been located. A scheme for the construction of a fish harbour at Karachi has been approved by the Government of Pakistan. This har-

bour is intended to provide all modern facilities for berthing of fishing boats, modern curing and other processing facilities for fish and fish products, ice and cold storage, and wholesale marketing of marine fish. Similar schemes for mechanisation of craft and gear, refrigerated transport, refrigerated markets and processing plants in other parts of the country are in their final form.

Private enterprise is also stepping forward, although rather slowly. A fish meal plant will go into production within the next month or two; another plant for freezing shrimps is expected to start operation before the end of 1953; and keen interest is being displayed by several concerns in the possibilities of fishing with mechanised craft and gear, of canning fish, particularly of shrimps, and producing vitaminous shark liver oil.

Implementation of the proposed development measures in fisheries will, no doubt, require considerable capital investment. On the other hand, the economic condition of the fishermen does not make it possible for them to invest in the development of the industry. Except a minor fraction, the capital so far invested has come from Government account and from the Colombo Plan and the U.S. Technical Co-operation funds. Recently Sweden has also offered some aid. Although pilot scale development plans may seem advisable at present some well-integrated overall policy will induce expeditions and increased flow of private capital into the fisheries industry. Effective efforts should be made to improve the economic condition of the fishermen so that they may themselves be in a position to invest in the development of the industry. In this respect the fishermen should be organized into cooperative societies. These societies should provide credits and link credits with purchase of necessities of the industry and of life on the one hand and the sale of the produce on the other.

Viewed in the general context of the economic and nutritional problems of Pakistan, and of the world food situation, the need for the development of fisheries in Pakistan cannot be over-emphasised. The development plans should be co-ordinated and integrated into an overall policy so that the development of the industry may serve the interests of the producers, the middlemen and the consumers alike.

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SOME FACTORS BEARING ON THE UTILIZATION OF MARINE PRODUCTS OF THE WEST COAST OF CANADA

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Fish and shellfish have been a food of man from prehistoric times. Remains of fish bones and marine shells exist in the débris of Pleistocene period European cave dwellers, and the kitchen middens of Recent period Indians of the coast of British Columbia are composed principally of clam shells with a few fish bones. Because of the ease with which they can be secured, shellfish probably attracted prehistoric man's attention before he recognized their edibility. Perhaps his first taste of fish followed seeing some animal or bird devouring a fish it had caught; seeking more of this delicate food, no doubt his first efforts at "fishing" consisted of picking up dead or stranded fish in shallow streams, on the beach, or in tidal pools. Soon (maybe a thousand years later) his growing inventiveness developed the first true fishing methods. One of the earliest must have been the placing of a barrier of stones, stakes or branches in a shallow stream, or a circlet of rocks on a tidal beach in imitation of natural tidal pools. The writer has seen such artificial tidal pools, constructed in modern times, still in use by the native British Columbia Indians not more than a hundred miles up the coast from Vancouver. The chronology of the invention of such fixed barriers, in relation to the invention of transportable fishing gear, is lost in prehistoric antiquity. Examples of fish spears have been found in prehistoric caves; nets and lines may have been used contemporarily but owing to their more perishable nature traces of them have vanished. Pictorial records of fishing nets antedate those of fish spears, and it is known that the spear, net, line, and rod flourished synchronously as early as the XIIth Egyptian Dynasty. The earliest picture of angling and hand lining is dated at about 2000 B.C.

Once adequate methods of capturing fish for food became developed, it is interesting to note the very great esteem accorded to fish as an article of commerce and diet in early historical times. The Bible alone contains some 80 references to fishing, fishermen, fish and other aquatic products, though curiously enough in no instance is any kind of fish

mentioned by name. It has been facetiously suggested that there had not yet been time after the Flood to assign names to the fishes, for because of the very nature of that catastrophe there was no necessity to make provision for the fishes when cataloging "every living thing of all flesh, two of every sort . . . male and female" as they entered the Ark. In the Indian legend of the Flood it was a fish, not a Deity, that gave warning of the coming deluge; a fish, not a dove returning with an olive leaf, signaled the recession of the waters and drew the ark-like vessel to rest on a northern mountain.

Among the many records of the popularity of fish the Bible account of the miracle of the loaves and fishes is well known. Fish played an important role in the food of the early Egyptians; King Rameses III was in the habit of presenting many thousands of fish to the temples for the benefit of the priests' employees and the populace, and Rameses IV maintained "officers of the Court Fishermen" whose duty it was to provide large quantities of fish for the monarch, his entourage and servants. Carefully mummified fish bearing a royal cartouche have been found, symbolizing the esteem bestowed upon them. The Egyptian city Latopolis was named in honour of the fish *Lates niloticus.* But it was in the heyday of the Greeks and Romans that fishes really came into their own as luxuries. Seas and rivers were exploited far and wide for their delicacies. Mullet, sturgeon and turbot commanded fabulous prices for the epicurian table. Pliny records that although mullet weighing under two pounds were plentiful and cheap, a large one was worth 8000 nummi (about $300), the value of nine bulls. The Greek comedians lamented that fish cost their weight in money, as was the case also in Rome. Martial upbraided a glutton who sold a slave for about $50 to purchase a dinner, then complained of its lack of variety because nearly all the money was spent for one mullet. At a Greek Attic feast, thirty-two kinds of fish were served; at a banquet given by the Roman emperor Vitellius in honour of his brother no less than 2000 choice fishes were served. A treatise of ten volumes on recipes for new dishes, attributed to Apicius, describes many sauces for fish, one of which calls for twenty-five ingredients. Some Roman nobles varied the custom of taking a cognomen from the name of a victorious battle by assuming a name derived from their favorite fish, e.g., Licinius *Muraena,* Sergius *Aurata.* Among the Greeks, Diogenes the Cynic died from the eager haste with which he devoured a raw polypus, and Philoxenus the Poet after dressing, cooking, and eating all but the head of a 36-inch polypus was warned by his physician that he had but six hours to live. Much later, King Henry I of England died from overindulging in his favourite dish of lampreys, a primitive fish at present much despised in Canada

and the United States because of its current depredations on the commercial fishes of the Great Lakes.

What precautions were taken in these early days to maintain the delectable qualities of freshly caught fishery products? History tells us that much of the fish was not cured in any way, and the need for keeping fish cool was already appreciated. Nehemiah, Governor of Judaea, complained in the Biblical book of his name about the sale of foodstuffs in Jerusalem on the Sabbath, including fish brought by the men of Tyre from the shores of the Mediterranean some 35 miles away; he caused the gates of Jerusalem to be closed to such commerce over the Sabbath, but later it was allowed that a special gate, called the "fish gate" should remain open so that fish could be sold before it would spoil. In Greece, runners were sent up the slopes of 8060-foot Mt. Parnassus to collect snow for preserving fresh oysters for banquets in nearby Athens. The Romans constructed huge vivaria or fish ponds in which to keep fish alive during warm weather until required for the table. Lucius Philippus had a tunnel pierced through a mountain in order to bring cool sea water to his vivarium; Hortensius Varro placed more importance on the coolness of the water in his vivarium than on the coolness of a draught of water for a fevered friend. Archimedes is credited with planning the construction of a large live-well, made of planks lined with lead, in the bow of one of the large vessels plying between Egypt and Sicily for the corn trade and carrying live fish in this well in which the salt water was constantly renewed by hand pumping. In early Egypt fish for the fresh trade were usually dressed on the boat and quickly dispatched to market. By New Testament times fresh fish were roasted, baked, or boiled; eggs were sometimes combined with the boiled type. But what of the fish that could not be transported fresh to market? The Egyptians were familiar with the process of splitting and salting then drying in the sun, and such salted fish, as well as pickled fish, were exported in baskets or barrels certainly as far as Palestine.

Turning now from ancient times in the Old World to more modern times in the West Coast of Canada, the native Indians of this coast prior to the coming of the white man had developed not only their clam fishery attested by the huge clam shell middens already mentioned, but also a considerable adeptness in catching fish, particularly salmon and eulachons. To preserve these fish for use out of season, salmon were cleaned, split, and subjected to a combined drying and smoking process in crude smoke houses; because the salmon ascends rivers to spawn hundreds of miles inland, many Interior tribes had access to this fish, though it lacked fat by the time it reached distant spawning beds.

Eulachons, a small, marine, smelt-like fish taken principally only in the river estuaries, were hung from the head on large vertical racks for open-air drying and when dried were so oily that they could be ignited and used as candles. Probably the earliest fishery by-product industry in what is now British Columbia arose from the craving of both Coastal and Interior natives for fish oil as a cooking fat and as a protective or ceremonial lotion for the skin and hair. The fish were allowed to undergo some decomposition to partially free the oil and were then boiled in wooden tanks, the liberated oil was floated and skimmed off and stored in animal skins or (after congealing) in closely woven jar-shaped baskets. Trade in this oil with Interior tribes developed the well-trodden "grease trails" over the lowest mountain passes and through the most suitable valleys into direct routes that would be a credit to a modern road engineer. These native fishing and preservation methods still persist on some parts of the coast, though the modern Indian has been known to visit an Interior cousin via his own automobile or a commercial airline, taking a token of eulachon grease either upon or with him, to the olfactory discomfort of any white passengers.

With the settlement of Canada's west coast by the white man, followed in 1858 by the establishment of the Colony (now Province) of British Columbia, a much greater exploitation of the coast's fishery resources began. Commercial salting of Fraser River salmon commenced as early as 1829 and by 1835 some 3500 barrels were being exported annually, principally to the Hawaiian Islands; salmon canning on the Fraser River began in 1870; fisheries for herring, trout, sturgeon, halibut, flatfish, dogfish, eulachon, seals and porpoises were reported by 1875. It is not the purpose of this paper to summarize the subsequent growth of British Columbia's fisheries or to describe the nature of the raw materials and the many processing methods used to turn these into finished products and by-products for local consumption, trade with the rest of Canada, or export. Government fisheries statistics commenced in 1876 are available for such purposes. Suffice it to state that the marketed value of British Columbia's fisheries in 1911 was $13,677,125, and in 1951 was $85,500,000, while the marketed values of the whole of Canada's fisheries for the same years were $34,667,872 and $200,125,000. British Columbia therefore contributes a very substantial portion to the total fisheries production of Canada, which exports more fish than it imports because it produces more fish than its population desires for their own consumption. The 13.7 pounds per capita per annum (1951) consumption of fish by Canadians is quite low in comparison with that of most other countries, even some not so richly endowed with fisheries of their own.

British Columbian and other Canadian fisheries, if encouraged by an increased desire on the part of Canadians to eat more fish per capita per annum, could meet this incentive and still continue to supply Canada's export markets with the kinds of Canadian fish products which the peoples of some other countries appear to appreciate more than do Canadians themselves. Why is there this lack of incentive of Canadians to appreciate and eat their own fish to a greater extent?

Apart from economic considerations such as the living standards of certain classes of Canada's population, and the present still-increasing costs of labour and materials that contribute to the retail cost not only of fish products but of other foods as well, some of the reasons for Canada's low fish consumption are:

(a) Living standards, including those for food, are relatively high; a great variety of raw and processed foods are available for competing with fish from the standpoint of the Canadian's purse and palate. Fish must be of high quality that will enjoy the confidence of the consumer before it will compete more successfully with other foods, particularly other animal products such as meat, fowl, and dairy products.

(b) Unfortunately, some past experiences of the Canadian adult generation with quality of fish products, particularly fresh and frozen, have not been too happy, and these impressions have been heightened by reminiscences of the previous generation concerning still unhappier experiences. Even in present-day Canadian and American popular literature including comic strips and cartoons, one sees the expression "something fishy about that" as synonymous with an undesirable state of affairs. "To draw a red herring across a trail" is still used figuratively to express the original literal idea that a somewhat rancid salted herring would effectively baffle bloodhounds tracking a scent. A cartoon or comic strip character carrying a parcel of fish (usually with wavy lines representing odour arising from it) almost always encounters some embarrassing situation, often resulting in the fish eventually reposing in a garbage can. Such allusions do not enhance the public's desire for fish. Unlike the enthusiasm of the ancients already mentioned, reference to fish is practically never used in America in a euphemistic sense. Meat, on the other hand, is frequently used in a laudatory and even euphemistic manner, e.g., "the meat of a subject" for the essence or truth of the subject; the word "meat" for the edible portion of even a vegetable product, such as "nut meats." Fish flesh is very seldom referred to as "meat."

(c) Fishery products in Canada, with the exception of canned salmon, canned herring and dry salt herring from British Columbia, and a few other products of the fisheries from the Central and Atlantic

Coast, are not subject to Federal Government inspection. Provincial sanitary regulations for fish processing plants apply in most Provinces, but do not always cover the products themselves. Voluntary inspection control is exercised by many processing firms, much to their credit, but unfortunately not by all to the same degree. This has an adverse bearing on the desirable confidence of the consumer of fishery products, mentioned under (a) above. On the other hand, meat products in Canada are processed under careful Federal Government control, and milk products receive considerable Federal or Provincial attention.

(d) Because of the bounteousness of many fishery harvests, not only in British Columbia but in other parts of Canada, there is an unfortunate tendency in times of glut to handle the raw product and its processing in a careless manner suggestive of the handling of cordwood, coal, or some other non-perishable material despite the fact that fish and shellfish flesh is more perishable than that of meat or fowl, which receives more careful attention. It is true that in times of extreme glut some of the raw material is diverted to manufacture of products such as fish meal and oil not intended for human consumption. However, there is ample advice available from technological sources to show the way towards better handling of fishery products during every stage from the time of catch to display for the ultimate consumer. Not all of this advice has been heeded.

(e) No matter how good may be the quality of a fishery product, particularly raw, fresh or frozen fish, there exists a certain aversion on the part of many ultimate consumers to the odours and other unpleasantnesses of preparing the product for the table. Many housewives complain of the odour of cooking fish, and families may enjoy fish cooked in a restaurant more than they would at home, in order to avoid this inconvenience. However, most people do not eat in a restaurant as often as at home. This aversion to the odours of cooking fish may be a matter of opinion influenced by hearsay, for many families cheerfully accept the somewhat faecal odour of cooking cauliflower.

(f) Some people just do not like fish. Vegetarians are included in this group.

To offset some of the above reasons for lack of appreciation of fish in Canada, it must be stated that while Canada has lagged somewhat behind some countries, particularly certain Scandinavian countries, in rigorous control over the quality of its fisheries products for both home consumption and export, it is well ahead of many other countries in this respect. Fisheries technological stations were instituted by the Biological Board of Canada (now the Fisheries Research Board of Canada) at Halifax on the Atlantic coast in 1925, at Prince Rupert on

the Pacific coast in 1926 (later moved to Vancouver in 1942), and on the Gaspé coast of Quebec in 1936. These stations, with the assistance of the Federal Department of Fisheries and the collaboration of Canadian fish processers, have gone far in the investigation of the basic principles underlying the utilizations of fishery products, and the applications of these principles.

The writer would draw attention, however, to the fact that not only some of the principles known to the Ancients, but also those developed through modern scientific research directed towards the handling and processing of fishery products in many countries, are sometimes overlooked or find delayed and slow application in the very countries where the principles were or are being evolved. Mention has been made of the opening of a fish gate on the Sabbath to allow fish to be sold in Jerusalem before it might spoil on further holding; in this so-called enlightened age there are still cases where fresh fish are held over for later sale to the detriment of its quality because of man's cupidity, where a hint from the cited solution might improve matters. The example of the Athenians in securing snow from Mt. Parnassus to preserve the delicacy of their oysters frequently is forgotten when fresh fishery products are transported long distances or held for considerable lengths of time without benefit of the crushed or "snow" ice now so readily available at many fishing ports. A publication only a month ago from the fisheries technological station with which the writer is connected described some experiments dealing with the transportation of freshly caught salmon in a tank of chilled sea water aboard the fishing vessel; already numerous inquiries have been received from Canada and several other countries for further details, yet it is merely an application of the cited invention of Archimedes in providing a tank of sea water on board a Roman vessel, and also almost a repetition of experiments carried out by another station of this Fisheries Research Board of Canada and published as a public Bulletin in 1931.

Other instances could be cited to illustrate the lack of application of known beneficial principles, freely published and readily available, but often forgotten, that could be used to good advantage in the handling and processing of fishery products from the West Coast of Canada, the rest of Canada, and elsewhere. But until more attention is paid to the condition and perishable nature of many such products, careless handling, gluts of raw materials, or undue haste in processing to fill a rush order will continue to give rise to instances of dissatisfied customers who will think twice before again buying a similar product.

As for the odours from the household cooking of fish, even high quality fish products certainly can give rise to characteristic odours, but

these should be considered just as normal as those from the cooking of meats, fowl, or certain vegetables. It is unfortunate that fish of slightly inferior quality causes cooking odours disproportionately more objectionable than those from a correspondingly inferior quality of most other food products. Means are known for mitigating the cooking odours from fish; among the simplest is dipping the fish or fish flesh in a dilute solution of lemon juice, or its counterpart of harmless citric or tartaric acid, just *before* cooking. Such flavour as may be imparted by the juice or the acids is practically indistinguishable from that imparted in the common procedure of squeezing a slice of lemon over the *cooked* fish.

In conclusion, it should be stated that despite what has been implied above concerning sometime deficiencies of quality and home consumption of Canadian fisheries food products, the West Coast of Canada's fisheries industries are well to the fore in the disposal of their waste materials not intended for human food. Good use of these materials is made in the manufacture of by-products. Descriptions of the processing, nature, and potentialities of these by-products have been given from time to time in publications from technological laboratories of the Fisheries Research Board of Canada and elsewhere, and current research is promptly reported. Among recent commercially developed by-products now receiving considerable attention are fish and whale solubles resulting from the press liquor recovered from the manufacture of oil and meal, and liquid or semi-liquid digests made by acid, alkali or enzymic action on whole fish or fish processing scrap. Both the above products are finding application in animal feeding and agricultural fertilizer fields.

FABRICATION, DEFINITION ET REGLEMENTATION DE LA SAUCE DE POISSON VIETNAMIENNE "NUOC-MAM"

Par J. Guillerm et A. Vialard-Goudou
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Les diverses populations d'Extrême-Orient, de l'Inde au Japon trouvent dans le riz la base de leur nourriture habituelle. Leur ration alimentaire peu sapide est complétée par des sauces azotées et salées qui en relèvent le goût et enrichissent les préparations culinaires.

Certaines régions utilisent l'azote emprunté au règne végétal, légumineuse comme le soja (Japon, Chine), d'autres l'azote d'origine animale des poissons ou crustacées (Cambodge, Indonésie, Laos, Philippines, Siam, Vietnam).

Le nuoc-mam du Vietnam qui nous intéresse ici, comme le patis des Philippines (Avery, 1950), représente une préparation liquide qui se différencie par son nom même qui veut dire "eau de mam" [1] des préparations pateuses dites "mam" qui sont à peu prés similaires au prahoc cambodgien, au padec laotien, au bagoong philippin, au trasi malais.

Le nuoc-mam, véritable denrée alimentaire nationale est préparé en de nombreux centres saumuriers le long des côtes du Vietnam depuis l'île de Phu-Quôc au Sud jusqu'à Cat-Hai au Nord.

Les grands centres de production sont ceux de l'île de Phu-Quôc et surtout de la province du Binh-Thuân avec son cheflieu de Phan-Thiêt.

En 1944, dernière année de statistique normale la production était de 75 millions de litres.

Il y aurait d'y ajouter le nuoc-mam fabriqué avec du poisson d'eau douce le long des rivières du Sud-Vietnam et dont la production augmente de jour en jour.

En 1914, sur la demande de l'administration, Rosé de l'Institut Pasteur de Saigon commenca l'étude scientifique du nuoc-mam.

Le 21 décembre 1916, les autorités administratives adoptant les conclusions de Rosé prenait le premier arrêté qui donnait une définition légale du nouc-mam et permettait de lutter contre la fraude.

Depuis l'industrie du nuoc-mam a fait l'objet de plus de 25 publications de toute une série de travailleurs de l'Institut Pasteur de Saigon.

[1] Cette expression peut se traduire plus librement par jus de poisson fermenté.

Fabrication Du Nuoc-Mam

La fabrication du nuoc-mam minutieusement décrite par Rosé (1918 a et b) exige des cuves, du poisson et du sel marin. En voici un résumé d'après cet auteur.

Poissons.—Une grande variété de poissons sert à la préparation du nuoc-mam, les plus petits sont les plus employés car leur lyse est plus rapide.

Les principales espèces péchées et identifiées par l'Institut Océanographique du Vietnam sont suivant Chabanaud (1924) et Chevey (1931).

Cá nuc Decapterus russelli-Carangidés.
Cá moì Dorosoma nasus et D. chacurda-Dorosomatinés-Clupeidés.
Cá lâm Spratelloides delicatulus-Dussumierinés-Clupeidés.
Cá lep Divers Septipinna et Engraulis-Engraulinés-Clupeidés.
Cá cóm Divers Stolephorus Engraulinés-Clupeidés.
Cá tap poissons de différentes espèces.

En dehors du Cá moì qui fournit une quantité appréciable d'huile, le Cá nuc et le Cá cóm sont les poissons de choix du saumurier.

Sel.—La qualité du sel est importante. Le sel le plus propre à la fabrication est le sel marin sec sans aucune matière étrangère. Le sel fin n'est pas à recommander. Le produit fourni par le monopole des Douanes et Régies renferme environ 25 p. 100 d'humidité et de sels étrangers où dominent les sels de magnésium.

Technique saumurière.—La fabrication du nuoc-mam se fait suivant les mêmes principes dans tout le Vietnam. Seuls varient quelques tours de main propres à chaque saumurier et qui déterminent le fumet, le "cru."

Cette fabrication peut se diviser en:

a) Mise en cuve du poisson et du sel.

Les cuves sont en général des récipients en bois (parfois en terre cuite) de forme cylindrique au tronc conique dont le volume varie entre 200 et 4000 litres. Elles sont munies à la base d'un robinet dont l'entrée est protégée par un filtre. On y place le poisson frais non éviscéré et le sel en couches alternées à raison de deux, trois ou quatre paniers de poisson pour un de sel.

b) Courte macération de trois jours environ qui fournit un premier jus rougeâtre appelé nuoc-bôi.[2]

Le nuoc-bôi est soutiré, placé dans des jarres ouvertes à l'air pendant un nombre de jours variable, puis replacé en entier ou par moitié sur la cuve. L'autre moitié, parfois réservée sert pour les lessivages. Après

[2] Boi: rejeter. Nuoc-boi: eau rejetée: jus non utilisable.

extraction du nuoc-bôi, la partie supérieure de la cuve est recouverte d'une couche épaisse de feuilles de latanier qu'on maintient solidement pressée à l'aide de traverses en bois fixées par des coins.

c) Soutirage du nuoc-nhut (premier jus).

La cuve ainsi mise en pression est laissée au repos pendant deux à six mois, robinet fermé suivant le poisson, le taux de sel, un premier soutirage donne un liquide de qualité supérieure riche en azote, de caractères organoleptiques très appréciés. C'est le nuoc-nhut que l'on vend en partie mais dont la plus grande part est le plus souvent utilisé pour couper les eaux de lessivage ou pour rendre marchand les produits trop pauvres en azote des derniers épuisements.

d) Soutirage du nuoc-mam.

Le contenu de la cuve alors épuisé par lixiviation donne le nuoc-mam. Cette opération s'effectue à l'aide de liquides de macération provenant de cuves plus anciennes, puis à l'eau salée à 25 p. 100 environ, elle est renouvelée plusieurs fois et fournit des produits de moins en moins riches en azote solubilisé. Lorsque l'épuisement est terminé, cette opération dure parfois plusieurs mois, le liquide de soutirage peu coloré est trop pauvre et on le laisse dans la cuve pour servir ultérieurement aux lessivages de nouvelles cuves.

Le résidu resté dans la cuve, constitué par le poisson épuisé est dénommé Xác mam. Il est utilisé tel quel comme engrais. Toutes ces opérations ont leur raison d'être, que les recherches de laboratoire de Guillerm (1930) ont permis de mettre en évidence.

La teneur moyenne en azote des diverses espèces de poissons servant à la fabrication du nuoc-mam varie entre 2,28 à 3,58 p. 100 du poisson frais.

Le rendement en nuoc-mam d'une cuve est conditionné par la qualité et la quantité du poisson qu'on y met, il est couramment de 70 p. 100. Le fabricant ne pourra extraire de sa cuve plus d'azote qu'il en a mis.

Le nombre de paniers de poissons peut servir de base au rendement et c'est ce qui se passe en réalité.

Essai d'industrialisation.

A part quelques sociétés vietnamiennes et chinoises, la fabrication du nuoc-mam constitue au Vietnam une industrie surtout familiale.

Diverses tentatives de développement de la production par l'installation d'usines disposant de moyens matériels modernes ont échoué, car la technique de fabrication généralement suivie consistait à exploiter divers brevets utilisant l'autoprotéolyse du poisson en milieu aseptique ou antiseptique.

C'est une erreur fondamentale car l'autolyse seule de la chair de poisson n'aboutit pas au nuoc-mam. Les caractères organoleptiques qui font apprécier ce produit par les consommateurs odeur, saveur, sont exclusivement dus à une fermentation microbienne, anaérobie stricte comme l'ont montré Boez et Guillerm (1930).

Definition et Caracteres du Nuoc-Mam

Le nuoc-mam est donc le produit résultant de la lyse de poissons avec fermentations limitées par la présence de sel marin.

Au point de vue scientifique c'est le résultat de la protéolyse du poisson frais dans une solution concentrée de sel marin protéolyse réalisée par les diastases des organes digestifs et par une série de germes anaérobies. En même temps que la molécule protidique se transforme en acides aminés, il prend naissance toute une série de corps provenant de la dégradation qui donnent au nuoc-mam son arôme spécial et ses propriétés apéritives et digestives tant prisées des Vietnamiens. (Vialard-Goudou 1953).

Le nuoc-mam résultant d'actions biologiques complexes est un produit à caractères variables tout comme le vin.

Les stades de la fabrication montrent en effet l'intervention de divers facteurs.

Ainsi s'il n'y a pas assez de sels, l'action des bactéries deviendra putréfiante avec augmentation de l'ammoniaque formée, s'il y en a trop, la protéolyse sera retardée. Un lessivage trop abondant donnera des produits pauvres en azote utilisable et de faible valeur alimentaire. Un soutirage trop rapide donnera un nuoc-mam qui se conservera mal par insuffisance de désintégration des protides.

Cependant un bon nuoc-mam représente certains caractères qui ne varient que dans des limites bien déterminées.

Quelle que soit la durée de la fabrication il n'est pas posible de dépasser la proportion de 75 à 77 d'azote dosable par la méthode au formol de Sörensen pour 100 d'azote total. Si la teneur en azote formol est inférieure à 50 p. 100 le nuoc-mam obtenu est instable; la moitié au plus de l'azote formol peut être sous forme ammoniacale: un taux plus élevé d'azote ammoniacal indique une désamination des acides aminés avec altération du produit.

La différence entre l'azote total et l'azote ammoniacal donne l'azote organique; la différence entre l'azote formol et l'azote ammoniacal donne l'azote des acides aminés. En outre un certain taux de sel, 25 p. 100 en moyenne, est nécessaire pour assurer la conservation du nuoc-mam.

Reglementation du Nuoc-Mam

Nous citerons simplement le dernier arrêté du 17 novembre 1943 qui reprend l'essentiel de l'arrêté du 21 décembre 1916. Voici les cinq premiers articles qui nous intéressent directement:

Article premier.—En Indochine, il est interdit de fabriquer, d'exposer, de mettre en vente et de vendre, sous la dénomination de nuoc-mam ou de nuoc-nhut ou des termes synonymes, tout produit autre que celui obtenu par les usages courants et loyaux de la technique saumurière traditionnelle annamite.

La dénomination de nuoc-nhut est réservée aux premiers jus des cuves, dont la fraction liquide est exclusivement constituée par l'eau de constitution du poisson.

La dénomination de nuoc-mam désigne les produits obtenus par la dilution du nuoc-nhut ou par l'épuisement des cuves à l'eau salée. Ces produits doivent répondre aux conditions exigées par les articles suivants.

Art. 2.—Les nuoc-nhut et nuoc-mam constitués par la dissolution de la chair de poisson à un certain degré de désintégration sont des solutions limpides sans dépôt appréciable, d'odeur et de saveur sui-généris, suffisamment salées pour ne présenter aucun indice de putréfaction.

Art. 3.—Les qualités substantielles du nuoc-nhut et du nuoc-mam dépendent:

1°) de leur richesse en poisson;

2°) du degré de désintégration de la chair du poisson;

3°) de leur valeur alimentaire.

La richesse du poisson est donnée par la teneur en azote total exprimée en gramme par litre.

Le degré de désintégration de la chair du poisson s'exprime par la teneur en azote formol qui doit être comprise entre 50 et 77 p. 100 de l'azote total.

La valeur alimentaire ou teneur en principes utiles exige que le taux d'azote ammoniacal ne dépasse pas la moitié de l'azote formol.

Le nuoc-nhut et le nuoc-mam fabriqués et mis en vente devront répondre aux caractéristiques suivantes:

Pour le nuoc-nhut:

Azote total	18 g. par litre au moins.
Azote formol	50 à 77 p. 100 de l'azote total.
Azote ammoniacal	50 p. 100 au plus de l'azote formol.

Pour le nuoc-mam:

Azote total	15 g. par litre au moins.
Azote formol	50 à 77 p. 100 de l'azote formol.
Azote ammoniacal	50 p. 100 au plus de l'azote formol.

Tout nuoc-nhut ou nuoc-mam dont le taux d'azote ammoniacal atteint ou dépasse 75 p. 100 de l'azote formol est considéré comme corrompu.

Art. 4.—Est autorisé: l'addition du sucre caramélisé ou non, mélasse, miel, thinh ou riz grillé dans les cuves de préparation.

Art. 5.—Sont interdits et considérés comme manoeuvres illicites:

a) la mise en cuve de poisson en mauvais état de conservation;

b) l'enrichissement des eaux de lessivage ou des nuoc-nhut et nuoc-mam par toute matière azotée autre que celle provement des cuves;

c) l'usage d'eaux de lessivage ammoniacales ou putrides;

d) l'usage des antiseptiques, des produits chimiques, des matières colorantes.

Cet arrêté supprime le privilège des nuoc-mam du Nord-Vietnam qui pouvaient contenir seulement trois grammes d'azote total par litre et établit ainsi une législation unique pour l'Indochine.

Peu après, l'arrêté du 29 mars 1944 fixa une période de transition de deux ans pour la teneur en azote total, soit:

11 g. pour le Cambodge, la Cochinchine et les provinces du Binh-Thuân, Khanh-Hoà, Haut-Donnai et Lang-Biang.

3 g. pour les autres centres de production.

Par décision du Gouvernement du Vietnam cette période de transition dure encore.

Resume

Pour permettre l'absorption d'une alimentation à base de riz, tous les peuples de l'Extrême-Orient l'additionne de sauces condiments salées à base de matières protidiques fermentées (soja ou poisson).

Au Vietnam, c'est la sauce de poisson "nuoc-mam" très voisine du "patis" des Philippines et dont la production annuelle en 1944 fut de 75 millions de litres qui remplit ce rôle.

Après un bref exposé de la technique de fabrication les auteurs rappellent que ce sont les travaux des chercheurs de l'Institut Pasteur de Saigon exposés dans plus de 25 publications depuis 1918 qui ont permis de fournir la définition et de fixer les caractères d'un bon nuoc-mam. Ils terminent en donnant la dernière règlementation qui peut intéresser les pays, comme les Philippines, où l'on consomme des produits analogues au nuoc-mam.

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STUDIES ON AGAR-AGAR IN JAPAN *

By T. Yanagawa [1] and K. Tanii [2]

Introduction

Agar-agar, a kind of carbohydrate contained in red algae belonging to *Gelidium* species, is one of the celebrated local products of Japan, manufactured by a special process which was developed in this country nearly 300 years ago. Numerous investigations have been made from the point of view of both applied and pure science.

We believe it advisable to commence with a brief description of the customary method of manufacturing agar-agar in Japan (1). The cleaned algae is first extracted with boiling water faintly acidified with sulphuric acid, and by natural cooling of the extracted filtrate, agar-agar hydrosol can be coagulated as a gel (1–2%). After it is cut properly it is placed outdoors in winter, so that the night cold freezes it, while during the day the warmth gradually thaws the frozen ice into water, which flows away. The last step is to dry it in the open air until the product is obtained in a final dry form. Chemical changes in the course of preparation have been investigated by Araki (2).

The above-mentioned process takes more than half a month and since it depends to a great extent on natural weather conditions, it must be considered unsatisfactory. In order to remove this drawback, several new methods have recently been devised, such as mechanical freezing or the application of heat from hot springs. The main problems to be solved are how to produce economically and efficiently a good quality product by mechanical means and how to produce agar-agar from *Gracilaria confervoides* by chemical treatment.

I. Propagation of Seaweeds Used for Agar-agar

Efforts have been made to promote the propagation of the seaweeds which are used as the raw material of agar-agar. For instance, the reefs were cleaned with simple implements so as to improve the production capacity of the growing areas and the growing areas were extended by submerging rocks and stones on the sea-bottom. Except in a few cases,

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however, these methods have not always been effective and further work must be carried out.

The seasons for spore formation and liberation have been studied by many authors. In *Gelidium Amansii* the tetra-spores begin to be shed late in spring when the temperature of the sea water rises to 21°–22°C., and the carpospores at temperatures of 24°–25°C. (3) (5). In *Gelidium fastigiatum* both spores begin to be shed at about 20°C. (4).

The liberation of the matured spores occurs almost every afternoon during the season. Sometimes about 100 spores per liter were founded in the sea water near a *Gelidium* field. The spores fix themselves on the rock surface after having lain in contact with it for about ten minutes (5).

The germination of spores and their later development into young plants have been reported on by Ueda and Katada (6) (11). According to their reports, some of them rise up erectly to form an upright bush, while others form creeping stolons which afterwards emit new upright buds.

The temperature ranges for normal germination were experimentally estimated at 10°–30°C. (optimum 25°–26°C.) in *Gelidium Amansii* (7) and at 10°–25°C. (optimum 16°C.) in *Gelidium subfastigiatum* (4). Low salinity (<1.020) delays the growth of primary rhizoids. Colors of the prevailing light seem to have some effect on the growth of the germ lings of *Gelidium*.

In the northern part of Japan negative correlation was found between the yields of *Gelidium* and the sea water temperature in winter, and *Gelidium* was not found in the sea where the minimum temperature fell below 2°C. (4).

Okamura (8), Ueda (9), and Ueda-Katada (6) obtained some data for the growth of *Gelidium Amansii* in the southern part of Japan. The plants are perennial. They grow very slowly in autumn, but rapidly in winter and spring, reaching lengths of about 10 cm. in the first year, about 18 cm. in the following year and more than 20 cm. in the third year. The annual yield amounts at a maximum to about 3 Kg. wet weight per square meter.

Okamura (8) found that small pieces of *Gelidium* plants regenerate rhizoids and continue to grow on a new substratum.

The researches on the relationship between *Gelidium* and other algae and animals living in association on the *Gelidium* field may be important, but the work on this subject is still incomplete. The young plants are damaged by being covered by algae such as various species

of *Corallinaceae* (10) and *Helposiphonia* (11). Some *Gastropoda* were found to feed on them (11). Research is now being carried out in co-operation with phycologists on the ecological relationship between *Gelidium* and *Corallinaceae*.

Some trials to "cultivate" these algae have been made. Kinoshita and Hirobe (12) were successful in seeding the spores of *Gracilaria confervoides* on an experimental scale. Fujimori hung the *Gelidium* plants on hemp-palm rope from a bamboo buoy in a calm inlet. He found that the plant grew twice as much in weight every month of the late winter as it had in the preceding month (S. Suto).

II. The Relation between Jelly-strength and Chemical Constituents of Agar-substances

Generally speaking, mucilages of red algae (geloses) are ester-sulphates of galactan, but there are in fact various kinds. After studying each gelose for each kind of red algae, the following results have been obtained: The more sulphuric acid is combined in it the weaker is the jelly-strength obtained, and vice versa. Sulphuric acid content varies widely from 1 to 25% (13). There are two kinds of sulphuric acid combined, one of which remains in the ash when the geloses are burnt while the other does not. Sulphuric acids are combined in geloses by two types, one of which is $R\text{-}SO_4\text{-}R'$ and the other $R\text{-}SO_4\text{-}M$ (R being polysaccharide and M metal). Analysing geloses of many kinds of red-algae, and representing the results on a graph having a mel-ratio of hexose/total SO_3 as its ordinate and that of total SO_3/SO_3 in ash as its abscissa, we get a line nearly parallel to the ordinate for geloses of all red-algae which have sufficiently strong jelly-strength to be utilized as material for agar-agar, and similarly we get a line parallel to the abscissa for geloses of red algae having little jelly-strength and which are utilized for stiffening textiles. At the same time, geloses of these kinds of red algae which have a weaker jelly-strength are found to be represented by a line located intermediately between the two above-mentioned lines (13). Moreover, when gelose (SO_3 ca. 9%) of a kind of *Gracilaria confervoides*, represented by the intermediate line, is treated with dilute alkali solution, a part of the sulphuric acid is easily separated, resulting in an increase of jelly-strength. Those which have 9% sulphuric acid are very weak in jelly-strength, but when the sulphuric acid content is finally reduced to 2% (comparable with that of agar-agar), jelly-strength increases remarkably so as to be comparable with that of agar-agar (14). It is also reported (15) that the addition of

$CaCl_2$ during alkali-treatment favors jelly-strength. Taking advantage of this, attempts have recently been made to manufacture agar-agar from cheaper material, e.g., *Gracilaria confervoides*.

III. Rheological Studies of Agar-hydrosol and Gel

a) *Visco-elasticity of agar-hydrogel* (16):—The experimental procedure adopted was that used by Schwedoff (1889), Hatschek and Jane (1926), and Poole (1926), the apparatus being composed of two concentric cylinders, the intervening gap being filled with gel and the inner cylinder being suspended by a tortion wire. When the top of the tortion wire is twisted, the rigidity G of the gel is determined; the elastic equilibrium is attained immediately, and the viscous flow commences, so that the inner cylinder is observed to move gradually.

Experimental results obtained are as follows. Elastic deformation is Hookeian in the range of strain studied (shear rate 0.1–0.6), and rigidity G markedly increases with the increase of concentration:

G(dyne/cm.^{2})	2.1×10^{-1}	4.3×10^{-1}	1.27	1.46×10	3.7×10^2
Conc. (%)	0.039	0.053	0.062	0.12	0.28

Viscous flow is anomalous; it increases along with the increase of shear strain, namely with the increase of deflection of the inner cylinder. The visco-elastic behaviour of agar-gel is described by the three-element mechanical model.

b) *Thermo-elastic property of agar-hydrosol* (17):—Aqueous solution of agar, gelatin, pectin, etc. or benzene solution of some metallic soaps make elastic jellies. The principal characteristic of these gel states is shape-durability and high elasticity in spite of a relatively high content of solvent.

The thermo-elastic property of agar-hydrogel was studied according to Meyer and Ferri's scheme (1935) for determining the elasticity of rubber. Thus, both the energy contribution and the entropy contribution to elasticity can be discussed from the stress-temperature curve under a constant strain.

The experimental device was the same as has been mentioned in the previous section (a). Experimental results show that the elastic force gradually decreases with increase of temperature. This means that the elastic force of gel is concerned with the increase of internal energy and also with that of entropy by deformation; this situation is similar to the behaviour of metals and crystals.

The nature of the high elasticity of gel seems to be somewhat different from that of rubber elasticity, which is chiefly attributed to the

decrease of entropy by deformation. The agar molecule is considered to be a galactan chain accompanied by sulphate radicals here and there. A lattice-like configuration of these poly-electrolyte chains in water might be the internal structure of the gel state.

c) *Viscosity of much diluted agar-hydrosol* (18) :—The gel-forming property of agar is so strong that even a 0.04% solution distinctly exhibits elasticity as has been described in (a), and anomalous viscosity is observed in these concentrations. Accordingly it is necessary to experiment with much diluted (under 0.04%) systems in order to test the purely viscous behaviour of the solution.

Measurements were made by the ordinary methods using Ostwald's visco-meter in the concentration range 0.01–0.04%, and $\xi sp./c$ (specific viscosity divided by concentration) were plotted against concentration.

$\xi sp./c$ decreases with the decrease of concentration, passes through the minimum, and then increases again with further decreases of concentration, and if a strong electrolyte such as KCl is added to the solution, $\xi sp./c$ decreases eventually with the decrease of concentration. This behaviour is the same as that of other poly-electrolyte solutions.

Intrinsic viscosity defined as $[\xi] = [\xi sp./c]c \rightarrow o$ is concerned with the extension of the molecule in the solution. And from the evaluation of the intrinsic viscosity of agar-hydrosol, it is supposed that this poly-electrolyte has a much stretched non-spherical configuration in water; $[\xi]$ of agar-hydrosol is much larger than that of the ordinary random-coil non-polar polymers.

IV. Organic-chemical Investigations on Agar-agar

Araki has investigated the chemical constitution of agar-agar. He isolated D, L-galactose and L-galactose (19) and reported on acetylated agar, heterogeneous composition, and percentage compositions (20) of agar-agar. L-galactose from methylated agar has been confirmed (21). 2,4,6-trymethyl-D-galactose, 2,4-dimethyl-3, 6-anhydromethyl-L-galactoside, 2-methyl-3, 6-anhydro-L-galactose dimethylacetal and pentamethyl-D-galactosido-3, 6-anhydro-methyl-L-galactoside have been isolated from methylated agar (22). 3,6-anhydro-galactose has been synthesized (23) and 3,6-anhydro-L-galactose has also been isolated from agar-agar (24) as its dimethylacetal by methanolysis of agar-agar and as its diethylmercaptal by mercaptolysis, from which 3,6-anhydro-L-galactose has been separated in free state. Again isolation and chemical constitution of agarobiose and isoagarobiose have been studied (25). A new disaccharide $C_{12}H_{20}O_{10}$ has been obtained by hydrolysing agar-agar with 1N

H_2SO_4 for an hour and has been named Agarobiose by one of the authors. The same substance was subsequently obtained from agar-agar as its dimethylacetal by partial methanolysis and as its diethylmercaptal by partial mercaptolysis, from which free agarobiose has been isolated respectively by the separation of methyl alcohol and ethylmercaptan.

It reduces Fehling's solution and gives α-methyl-D-galactoside and 3,6-anhydro-L-galactose dimethylacetal by methanolysis with 2% HCl-CH_3OH. By preliminary treatment with 0.5% HCl-CH_3OH and further methylation with Purdie's reagents, agarobiose gives hexamethyl-agarobiose dimethylacetal (b.p. 155–6°/0.052 mm., $[\alpha]_D$ — 11° [H_2O]). When this methylated derivative is left in 1N H_2SO_4 at ordinary temperature for 182 hours, it is changed to hexamethyl agarobiose, $C_{12}H_{14}O_4(OCH_3)_6$, $[\alpha]_D$ — 4.4° (H_2O).

As hexamethyl-agarobiose dimethylacetal gives 2,3,4,6-tetramethyl-methyl-D-galactoside and 2,5-dimethyl-3,6-anhydro-L-galactose dimethyl-acetal by methanolysis with 2% HCl-CH_3OH, it can be concluded that the hexamethyl-agarobiose dimethylacetal is 4-2,3,4,6-tetra-methyl-D-galactoside<1,5>-2,5-dimethyl-3,6-anhydro-L-galactose dimethylacetal. Further, from the fact that the specific rotatory power of the acetal is small, it can be assumed that the sugar is a β-galactoside. Therefore, the chemical constitution of agarobiose is illustrated by Figure A:

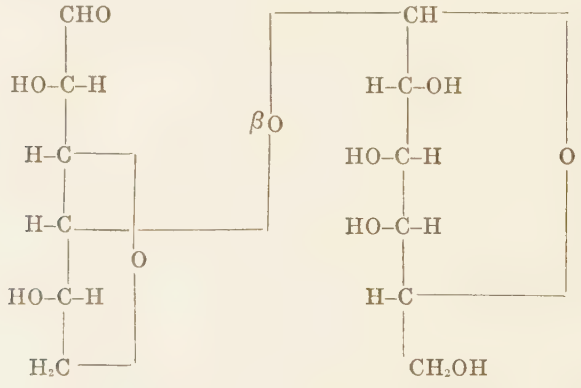

FIG. A.—Agarobiose

The constitution of agar-agar together with the mechanism of the formation of 3,6-anhydro-L-galactose in marine algae was discussed (26). Taking into consideration the isolation of 2,4,6-trimethyl-D-galactose and 2-methyl-3,6-anhydro-L-galactose from the methylated agar by hydrolysis as well as the isolation of agarobiose from agar-agar by partial hy-

drolysis, it may be possible to conclude the existence of the above linkage (Fig. B), in the molecule of agar-agar (26):

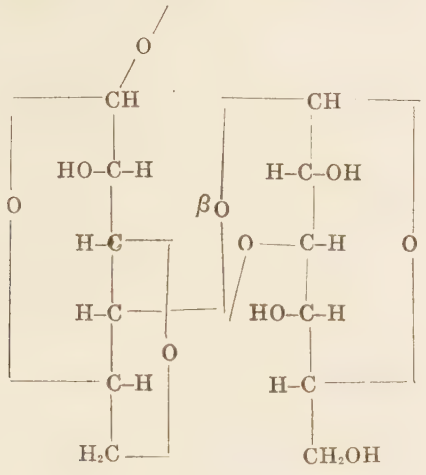

FIG. B

Further it must be mentioned that the partial methanolysis product of agar gives about 50% of agarobiose dimethylacetal.

The above-mentioned experimental results cannot be explained by the formula proposed by Jones and Peat (1941), showing that nine residues of D-galacto-pyranose are combined mutually by 1,3-glycosidic linkage and at reducing end of D-galactose residue joins L-galactose-6-sulphate or 3,6-anhydro-L-galactose through 1,4-linkage, but rather it may be explained better by the assumption that in the molecule of agar, agarobiose units are repeated.

Comparative studies on the chemical constituents of agarous substance of *Gelidium Amansii, Campylaephora Hypnaeoides, Acanthopeltis Japonica,* and *Gelidium subcostatum* have been reported.

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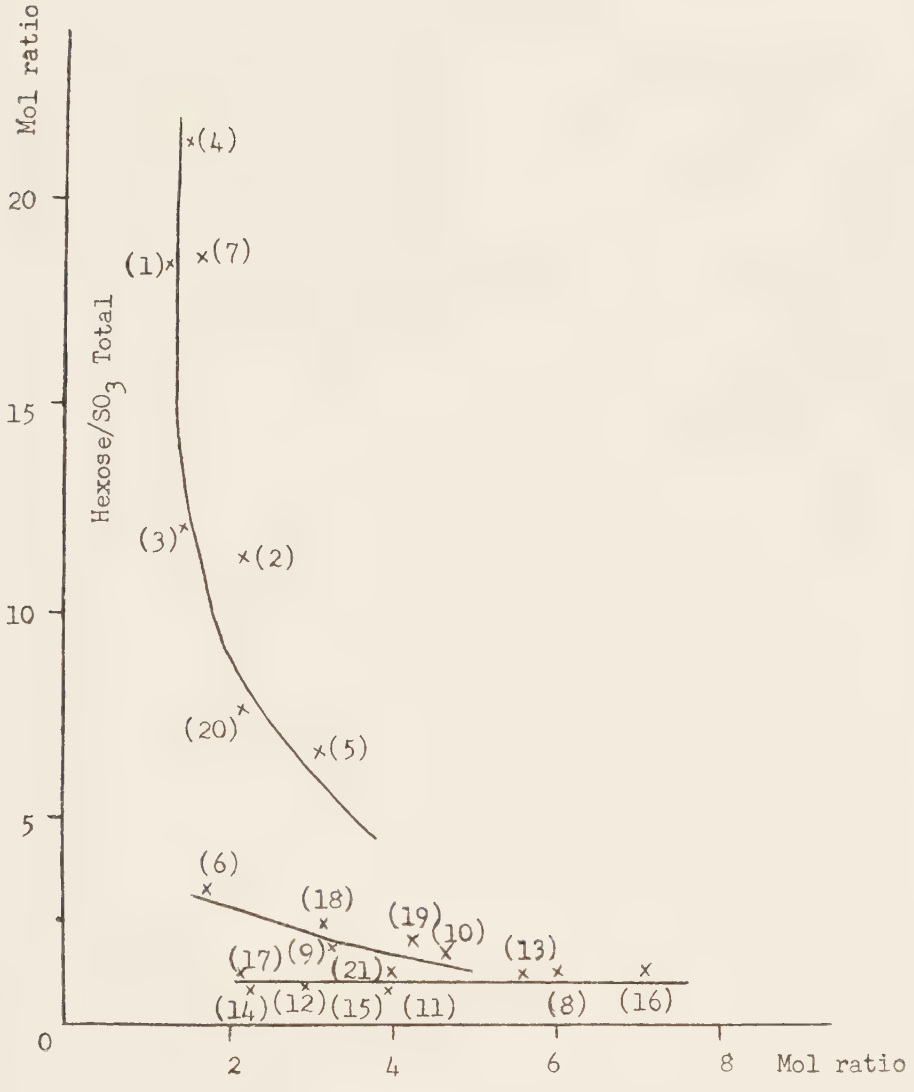
Mol ratio
Hexose/SO_3 Total
20
15
10
5
0
2
4
6
8
Mol ratio
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
(11)
(12)
(13)
(14)
(15)
(16)
(17)
(18)
(19)
(20)
(21)

A REPORT ON THE STUDIES MADE IN JAPAN ON PEARL CULTURE

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The culture of pearls in Japan dates from 1893 when K. Mikimoto first produced by culture blister pearls from *Pinctada martensii* (Dünker). Then in 1904, T. Mise first succeeded in cultivating spherical pearls. He was followed by T. Nishikawa and K. Mikimoto, but it was not until 1915 that M. Fujita organized Nishikawa's method on an industrial basis and brought the products to the market. In 1938, the total production at 289 culture grounds reached a peak of 560 kg. per annum. After this the production slumped and the number of culture grounds was also reduced to 106, which were even closed entirely at one time. However, the recovery starting from 1948 was spectacular, and in 1952, the number of culture grounds exceeded 1200 with a total output of 400 kg. a year. The fresh-water culture of pearls has also been continued since it was successfully experimented on *Hyriopsis schlegeli* (Martens) in 1924, and now has an output of about 4 kg. a year.

Until recently the method of pearl culture had been veiled under the protection of a patent. But the increasing demand after 1946 made it imperative to reorganize the industry on a scientific basis. Thus the Nippon Culture Pearl Co., Ltd., which is the organization of Japanese pearl culturists, established a laboratory to carry on basic studies on pearl and its culture, in close cooperation with Kyoto University. The laboratory afterwards became independent and was reorganized into its present form. At present there is a project conceived by the Government for setting up the National Research Institute so as to meet the marked increase of the numbers of both the culturists and the scientific workers.

The most important task in the study of pearl culture is to find out the process in which a pearl is formed. The Japanese pearl culturists, having developed a high art, seem to have accomplished this task. But it is plain, if you observe how pearls are formed under natural circumstances, that while they found out a method of transplanting pearl secretion tissue, they have not yet clarified the whole

process of pearl formation. K. Isowa tried an experiment on *Pinctada martensii* and obtained a number of seed pearls by giving chemical or physical stimuli to its aductor muscle and anterior retructor muscle, and patented his method. Y. Matsui, working with Isowa, supposed that a substance similar in function to a hormone was first formed by the stimulus of a wound, and this hormone-like substance in its turn caused abnormal propagation and functional reverses of the epithelial cells in the mantle. On this hypothesis, he made various experiments with fruitful results. As a result of his histological studies of the mantle tissues of *Pinctada martensii* and *Hyriopsis schlegeli*, Y. Ojima identified four kinds of secretory cells, but after testing the calcium contents in the tissue, he concluded that these did not make the glands specialized for secreting calcium. Ojima and T. Watanabe are now engaged in the study of the structure and the process of formation of the pearl sac. I. Kawakami transplanted the mantle tissue of *Pinctada martensii* in the gonad tissue, and saw the outer epidermis propagate and complete the formation of pearl sacs in fifteen days, while other tissues degenerated. He also reported his studies on the regeneration of the mantle.

With regard to the formation of pearls, the important question that the scientists must answer is: What is the mechanism of the calcium deposition as well as of the shell formation? Our recent efforts have been directed to discovering a new explanation to answer this question.

Y. Matsui, S. Tanaka and Y. Uchida are now carrying on experiments on the calcium deposition in *Pinctada martensii* and *Hyriopsis schlegeli*, using the isotope Ca_{15}. When the animal was kept in water containing Ca_{45}, the Ca_{45} absorbed in the internal organs, with the exception of the liver, reached a maximum at the fifteenth hour and no change was observed at the thirtieth hour. In the mantle, the maximum was reached at the sixteenth hour and a reduction was observed at the thirtieth hour. In the shell and the pearl, the presence of Ca_{45} was noted at the fourth hour. When Ca_{45} was injected in the body of the mollusc, it was diffused in the internal organs in 1–2 hours and began to be excreted out of the body at the fourth hour. While the shell is mainly composed of calcium carbonate, it also contains a certain amount of conchiolin, which is an organic matter. Many points as to the attributes of the conchiolin are yet unknown. S. Tanaka and H. Hatano have undertaken a biochemical study of the conchiolin, which has led them to discover that the conchiolins in both the shell and the pearl are of the same composition and that proline, oxyproline and sulphur contained amino acid are found in either of the two,

while halogen contained amino acid as gorgonin and spongin, are absent. Y. Matsui, M. Takanami and T. Hirota measured the amounts of amino acids in normal and baroque pearls in a microbiological assay and found that while there was no difference in the amounts of acidic amino acids between the two pearls, there were significant variances in the basic amino acids: namely, in the normal pearl layer, glycine registered 21.9% against 9.8% and leucine 16.4% against 11.3%; and in the abnormal layer of baroque pearls, histidine registered 4.7% against 0.5%, arginine 8.3% against 4.9%, lysine 7.4% against 1.7%, threonine 1.9% against 0%, etc. D. K. Ikenaga, who modified and employed Clark's method, manometrically ascertained that there was a variation in the activities of carbonic anhydrase in *Pinctada martensii,* corresponding to the specific organs and age of the animal and the seasons of the year. T. Tsuji demonstrated by a histochemical study that while carbonic anhydrase was almost absent in the epithelium on the inside and at the top of the mantle, it was found in abundance in the epithelium contiguous to the shell. He is also carrying on a study on the distribution of nucleic acid. Y. Ojima and Ikenaga, who have undertaken a histochemical study of the alkaline phosphatase in the mantle and the pearl sac of *Hyriopsis schlegeli,* have discovered that it is distributed in a remarkable amount in the epithelium at the top of the mantle and that while it is found neither in the mucus glands at the side of the mantle adjacent to the shell nor in the epithelial cells of the pearl sac, a considerable amount of it is present in that part of the tissue which has been injured by the insertion of a pearl nucleus.

Physiological and ecological studies of pearl oysters are also being carried on with great animation, as these can be directly applied to the culture of pearls. Examples are S. Mori's study in the respiratory physiology and daily rhythmic activities of *Pinctada martensii,* I. Honjo's study concerning their reaction to light, N. Kawamoto's study of the artificial spawning in ordinary and diluted sea water, H. Kobayashi's and J. Matsui's experiments with various degrees of the salinity and temperature of sea water and other environmental conditions, and the studies taken up by S. Kobayashi and the staff of the Mie Prefectural Fisheries Experimental Station on the generation and larva of *Pinctada martensii.* C. Ashikaga, S. Tanaka, H. Hatano and others have made a number of reports on their studies of the chemical composition and its variation according to the seasons of the year.

Researches into the water, the bottom of the Pearl Culture ground and the plankton are proceeding under the collaboration of Y. Toyohara, J. Yamaji, M. Motojima, M. Morishima, Y. Inoue and others.

Earnest hopes are attached to these researches in view of the degrading tendency of the qualities of the products due to the recent increase in the number of pearl culture grounds.

An important aspect of the art of pearl culture is concerned with the scientific evaluation of the quality of a pearl. For this, it is indispensable to clarify the essential properties of pearls through physical and chemical approaches. Y. Uchida and M. Ueda made clear the interrelation between the stratiform makeup of the pearl and its irridescence. T. Watanabe is engaged in a research into the interrelation between the color and the thickness of a pearl layer and also into the crystallization of the substance. Y. Matsui and T. Hirota have reported that there is a marked difference in the crystalline form between the normal and the baroque pearls.

Y. Uchida discovered by spectroanalysis that there were remarkable differences in the mineral contents among pearls with different colors. T. Kosaki's report has disclosed that a pearl contains 16–66 μ/100g of porphyrin and 5–70 μ/100g of metalloporphyrin, varying with the color.

Recently our laboratory has been made the center of the studies devoted to the discovery of the conditions on which to evaluate the qualities of pearls scientifically. With the help of Hardy's self-recording spectrophotometer, T. Fukuda and his collaborators examined pearls with various colors and lusters, and have proved the possibilities of classifying them according to their substantial colors. They have also demonstrated that they can calculate the thickness of the pearl layer by rating the surface color which is formed by the interference of a reflexion. Besides these studies, various other approaches are now being tried to test the pearl as a jewel.

FUNDAMENTAL STUDIES ON THE FISH LAMP

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It is a well-known fact that animals react to light, positively or negatively. Phototaxis of protozoa such as *Paramecium* and *Euglena* has been studied by many investigators, and reaction of the earthworm to light is also a well-known fact. Especially for insects, most efficient lamps were recently discovered by means of studying complex factors between visibility of retina of their eyes and their behavior.

Fish lamps have been used in every country in the world since ancient times to increase efficiency of fishing. In Japan, the torch-light has been used since olden times for collecting the fishes. Nowadays, electric fish lamps are employed by almost all fishermen in our country. However, maximum efficiencies could not be expected because of unreliable theories about fish lamps. Dr. M. Tauchi (1926) and Dr. T. Sasaki (1950) studied the effects of fish lamps upon fish shoals in the sea, but the studies of the two investigators were chiefly on the side of physics, and biological aspects were not fully considered. Therefore, the fundamental reason for the method of using fish lamps was not yet clear.

Since 1947 the writer has studied, with co-investigators, the relation between fish behaviour and fish lamps, using methods of physiology and experimental zoology.

For these experiments, many kinds of young marine fishes were used and their reaction against various kinds of light in the dark room was determined. Studies were made of the behaviour of adult horse-mackerel in a rectangular net which was set down off the coast of the sea in front of the Ichthyological Research Institute, Shimoda, Izu peninsula, Japan.

Experiments

In the laboratory, the writer adopted a lusterless, black, round wooden tank, which was 100 cm. in diameter and 25 cm. in depth; and the tank was divided radially into eight compartments, which were open to each other at the center. The tank was filled with water to a depth of 20 cm. and a color filter, was placed over a light window of each compartment and 60-Watt Mazda electric bulbs were set 20 cm.

above each of them. In order to make the illumination for the colored lights equal to 50 lux on every water surface of the eight compartments, some sheets of white paper were piled up over these filters for adjusting the light. The color filters were arranged in two ways, one in the order of wave length and the other at random in order that the fish might not become familiar with the color arrangements.

We observed the rates of frequencies of the time of entrance of the fishes into each compartment of various lights, and compared the rates with the relative energies which were calculated by the transparencies of the filters, sensibilities of selen photometer and radiant energies of the lamp, and judged their phototaxis tendencies. By this method, we got considerable experimental results and will show the abstract of these as follows:

One of my co-workers, Dr. Osaki, studied the relation between the phototaxis and the aggregation of young marine fishes, because, in a biological phenomenon, the aggregation frequently comes into question. Some investigators who have studied on the fish aggregation, have probably made the assumption that apparent gatherings are real aggregations. Nevertheless, it is possible that two fishes actually form an aggregation even when they are so apart from each other that they may be considered as a group. Therefore, it is next to impossible to conclude from the appearance whether a gathering is an aggregation or not. In our studies on the phototaxis of fish, it is necessary to conduct research on how aggregation affects the phenomenon and what difference exists between the phototaxis of the individual fish and that of the aggregated fish. The shape of the curves of fish gathering rate varied in accordance with the number of fishes employed and wave lengths in the experiments, but, at any rate, fishes are constantly forming various types of aggregation, the shapes of gathering rates of each individual were at random, while those of two or more numbers of fish in an aquarium coincided with each other and maximum values of these appeared at the range of green and blue colors in common fishes (Dr. H. Ozaki).

The types of phototaxis of fish were found to be divided into two. One was the greatest fish-gathering rates in the range of wave lengths of green and blue as were seen in *Oplegnathus, Monacanthus, Cybium, Spheroides* and *Sphyraena,* while the other was quite contrary as in *Anguilla* (M. Takeda).

The product of radiant energy of light of certain wave length and the visibility of eyes to that light was called "Spectral luminosity" for the same wave length; and when the spectral luminosity was calculated by using the human visibility curve with the maximum displaced suitably as a substitute for the true visibility curve of eyes of fish, it turned

out that the ratio of the fish gathering rates for the two lights was proportional to the ratio of the spectral luminosities of the two lights. Moreover from the ratio of spectral luminosity to radiant energy, the "visual efficiency" was calculated, and in the case of *Spheroides rubripes*, green light showed the largest visual efficiency, that of blue light was next to green, and that of red light was smallest.

Though radiant energy of red light was 22 times as much as that of green light, its visual efficiency was no more than 1/62 of that of green light (J. Konishi).

Studies on the influence of repeated experiments on the aggregation of fish to a fish lamp were carried out; the young *Girella punctata*, which was repeatedly made at intervals of ten minutes, made clear that the influence of a preceding experiment was held over to the succeeding one, while in the experiment of young *Scomberomorus niphonius* made at intervals of 30 minutes, no such influence was seen, and the fish gathering rates of *Scomberomorus, Oplegnathus* and *Monacanthus* under the stationary light attained maximum in a definite time, and then became stabilized at this maximum value (H. Kobayashi).

The experiment of turning on and off at any intervals two lamps which were situated inside the water tank (3 m. in length, 64 cm. in width, 40 cm. in depth) was done. *Aplocheilus latipes* (fresh water fish) and *Girella punctata* showed the greatest gathering rates to the lamps, which had the most appropriate intensities for them when two lamps were turned on and off. However, the gathering rates, as a whole, decreased little by little in proportion to shortening of the interval (T. Niki).

The gathering rates of *Spheroides* and *Mugil* show almost the same tendencies of sectional distribution as the type U in the limited length of water tank (3 m. in length, 25 cm. in width and depth) and the light source set at the end of it, used in this experiment, the type U of the curve of sectional distribution of fish in the tank is divided into two meanings; and those are positive gathering rate which decrease exponentially in proportion to the distance from the light, and negative gathering rate which, on the other hand, increase exponentially to the opposite side of the light. The value of the light intensity at which fish gathering rates are highest was 55 lux in *Spheroides*; both in the day and in the night, the values were 15 lux in the night and 87 lux in the day in *Mugil* (S. Nagata).

The present writer further studied with K. Uno on the influence of the moonlight on the gathering rates to the fish lamp as follows:

The relation between the moonlight and the fish lamp upon the gathering rates of fishes has been studied in the laboratory and in the

open sea, as no experimental studies had been carried out, although such relations were commonly discussed.

Laboratory experiment:

In a black colored tank, 1 m. in diameter, 20 cm. in water depth, a 20W electric bulb was set so as to throw its light horizontally in the water, on one side of the tank called F-light, after fish lamp and the other one, called M-light, which compared to the moonlight was attached 2 meters above the water surface. The light showed 0.068 lux on that surface as the light intensity of the full moon on the surface of the sea was measured from 0.06 to 0.07 lux.

Under these equipments, the gathering rate of fish to the F-light was calculated for fifteen minutes at water temperature of 13°–14°C in the dark room.

From the experiments of the gathering rates of fishes to the F-light under varying intensity of the M-light in different species of fish, it was found that the gathering rates of *Girella punctata* had almost the same in either one light or two lights, while those of *Pempheris japonica* were more considerably decreased in the two lights than in one.

And the result of the experiment on *Spheroides niphoblse* coincided with that of *Pempheris* in spite of change in the intensities of the M-light. It was observed that the gathering rates of fishes decreased in the field of F-light according to the increase of intensity of the M-light; and the rate increased in the field of green color of the F-light and decreased in the red of it.

From the experiments above mentioned, the relation between the gathering rates of fish and spectral luminosities which were calculated from the product of the relative radiant energies in place of the light intensities and relative visibilities for light of the same wave lengths, (Kawamoto and Konishi, 1952) will be shown as the following equation:

$$\frac{Ga}{Gb} = \frac{Ha}{Hb}$$

where Ga and Gb are the values of rates of fish gathered under the F-light and the M-light except in the field of the former respectively, and Ha and Hb are the spectral luminosities under the fields of the two lamps.

Open sea experiment:

A rectangular net of 20 m. x 6 m. x 3 m. was let down off the coast about 200 meters from the shore near our Ichthyological Laboratory and ten horse-mackerels (*Trachurus trachurus* L.) about 16 cm. in body length and 30 gm. in body weight were set free in that net at the time of each experiment.

At one side of the net, a fish lamp which directed horizontally toward the other side was fixed one meter under the water from the surface and a 20W, 60W or 100W electric bulb was used as a light source of the fish lamp, and attached to it was a green glass filter 18 cm. in diameter which had a limit of transparency from 500 $m\mu$ to 570 $m\mu$ and maximum wave length of transparency of 530 $m\mu$.

The weather was frequently stormy during the experiment, as this study had to be carried out from November to February in 1950–1951, and difficulties had often been experienced for observing the phenomena in the roughing sea. The water temperature measured from 14.0° to 15.5°C in these experiments.

The numbers of fish which gathered in the area of light field within three meters from the lamp were calculated as the rate of gathering for twenty minutes in every thirty seconds.

In the dark night experiments, the gathering rate attained about 80% within the time of two minutes and 30 seconds after the light was switched on, and continued its rate at the light source of 20W of the fish lamp.

The rate of gathering in the night of the moon age of 9.8 decreased to 77.8% as compared with the data of the rate of gathering in the dark night and, moreover, decreased to 21% at the moon age of 10.7.

The rate became zero at the 11.8 moon age, and no reaction of fish to light was seen.

As the light intensity of 11.8 moon age was almost equal to that of 18.0 moon age, it might be supposed that the fish would not show any reaction to the fish lamp in the period between those two ages.

From these experiments, observation was made that the conditions of gathering rates of fish differed according to the kind of bulbs, 20W, 60W, or 100W respectively, and it was considered that the 20W electric bulb was most adequate in the limit of the size of this experimental net, since the rates of gathering became irregular in the light sources of 60W and 100W.

It turned out clearly that the effect of the fish lamp was influenced by the moonlight from the results of experiments in the laboratory and in the open sea; however, the authors concluded that the efficiency of it might be kept in some limit by adjusting the strength of intensity of the fish lamp. But the relation of those intensities has not as yet been sufficiently studied, and it will be cleared in a later experiment.

In the course of these studies, it was also understood that the efficiency of the lamp was considerably influenced by facts such as the tidal current, direction of wind, and temperature of the sea water, etc.; and the relation of these factors to the lamp will be studied later as those must never be passed over.

COACTION IN LAMP-COMMUNITIES

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Besides many investigations relating to the fish-gathering lamp on such items as the light source, condition of light in water, phototaxis of fishes and the methods of fishing, there is an interesting ecological article worked by Hardenberg (1935) on shoals assembling around the lamp. The effect of the fish-gathering lamp is nothing but merely a simple artificial change of the light, one of the physical environmental factors, to gather fishes. Thus, the mechanism of gathering fishes is considered to be based primarily on the phototaxis of some animals. It is, however, quite uncertain whether the behaviors of animals in the natural environment, which appear as the results of complex interaction of many factors, may accord or not with those observed in the laboratory under special experimental conditions, namely, only one individual or one sort of fish is treated. It is reasonably expected that the coaction of fishes may be modified by light and that the existence of different sorts of animals may cause the phototaxis for some fishes. For instance, fishermen use "shirasu" (larval fish, particularly sardine or anchovy) or mysids as food for fishes to keep the shoal stable under the lamp; zoo- and phyto-plankton feeders, such as *Engraulis* and *Stolephorus*, are changed into pure zoo-plankton feeders under the lamp and take smaller planktonic crustaceans assembling around the lamp, and some fishes showing the negative phototaxis in experimental condition, many benthonic fishes and higher predators, may act photopositively under the lamp where many prey animals are assembling. Thus, the coaction between fishes around the light under the natural condition must be investigated at first, when we research the cause of the fluctuation found in caches by lamp method. The effect of light upon fishes from the synecological point of view will be understood correctly solely when the interrelation of animals under the light is fully compared with that under the non-light condition. However, I can here refer only to the phenomenon observed under the lamp.

In the following, I wish to give first the outline of coaction of lamp-communities taking the most complex case observed in Shirahama (Wakayama-ken) as an example, and then show briefly some

examples of more simple cases which are considered to lack some social components.

A. Prey and predators coexisting with the object fishes.

The observations were made in the area near Shirahama situated on the west coast of Kii peninsula and strongly influenced by a branch of the warm current "Kuroshio." Animals assembling around the lamp are synecologically classified into the object, fishes, preys, and predators. Reviewing the data obtained during a series of investigations on food habits and behaviors of fishes around the lamp to find the niches of main fishes in lamp-communities, the lamp-animals are classified into the following five groups:

1) *Prey animals:* This group consists of Gammalid amphipods, megalopae, mysids and *Engraulis* of Shirasu stage, and represents the lowest class in the temporal communities formed artificially under the lamp. It contains no producer or smaller preys nourishing the animals mentioned above. Members of this group are eaten chiefly by the secondary predators, although a part of them serves as the food of the primary predators.

2) *Primary predators:* This group consists of *Stolephorus, Engraulis* and *Pempheris,* of which the former two are said to be zoo- and phyto-plankton feeders in the natural environment, but are changed into pure zoo-plankton feeders under the light. Stomachs of the most examined individuals were, however, almost empty.

3) *Secondary predators:* This group consists of medium- or large-sized zoo-plankton feeders, *e.g.* carangids and mackerels. These members feed chiefly on the prey animals and occasionally on the primary predators.

4) *Tertiary, quaternary and end predators:* The primary and secondary predators which form the chief object of the lamp fisheries are dispersed from the light by the emergence of tertiary and higher predators. Consequently, fishermen hate their visits very much. Especially the end predators, which occupy the highest position in the food-pyramid of the lamp-community, may be called the destroyers of the lamp-community, since the fishes disappear completely at the appearance of members of this group. The lower predators form compact shoals and move along the circular rout around the lamp, perhaps along the equi-luminous line, while predators of the higher degree usually visit the lamp in a single individual, move across the equi-luminous line and take food actively under the light. The tertiary predators are composed of squids and *Sphyraena,* the quaternary predators of Trichiurids. The end predators in shallower water are composed of *Squalus, Coryphaena* and *Dolphinus,* of which the latter two are much

rarer than the first, while those near the bottom are represented by *Epinepherus* and its allies.

(5) *Indifferent group:* This group consists of the fishes which have no significant relation to other animals on account of their meagre population, short staying time under the light, and the fact that they seldom eat or are eaten near the lamp. Some members of this group occupy the situation between the lamp fishes and those not assembling around the light; some others show enormously strong phototaxis, Crabs, *Atherina, Cypserulus, Mugil, Euthynnus, Tylosurus, Teuthis* and *Ostracion* are the main members of this group. The following four inclinations are deducible from the above-mentioned classification.

1. The size of a lower rank is, in general, smaller than that of the higher rank. The fishes of the younger stage belong to a rank lower than that of its full-grown stage.

2. The fishes of the lower rank take the food lower than that of the higher fishes.

3. The fishes of the lower food rank are controlled more strongly by the light.

4. The fish with a stronger dispersing influence on the community is placed in the higher rank.

Generalizing these inclinations, we may be able to determine the niches of main lamp-animals as follows: (small planktons can not be assembled by the light in the streaming tide) — smaller planktonic crustaceans (*Oncaea venusta* and *Calanus*) — larger planktonic crustaceans (megalopae, Gammalid amphipods and *Siriella*) — *Engraulis* of Shirasu stage — *Stolephorus* — *Engraulis* — (Clupeidae) — *Pempheris* — Carangidae — *Sphyraena* — squids — *Trichiurus* — *Squalus Coryphaena* — *Dolphinus.*

The lamp animals and those not assembling around the light can not be separated distinctly from each other, but they are connected completely by the existence of many fishes showing various degrees of tendencies to assembling around the light. The distance between these intermediate fishes and the lamp-animals may be determined by the stability of the shoal, coaction to other animals and other behaviors of the former. Thus, the primary predators assembling around the light and the fishes of the same rank not assembling near the lamp are continued which each other by a series of the following intermediate fishes — *Atherina* — *Cypserulus* — *Mugil* —; in the secondary predators the series is represented as — mackerel — *Sarda* — *Euthynnus* — (*Katsuwonus*) —; and in the tertiary predators it is — *Tylosurus* —. Similar

relations can be expected also in the benthonic fishes, although they can not be ascertained easily.

If the above-mentioned relations are correct and of important ecological significance, there must be a lot of phenomena reflecting these relations distinctly. The social structure of the lamp community and the arrival order of various animals near the lamp may be accepted as good examples of these phenomena.

When the lamp is lighted, many animals assemble one after another and after a certain time they attain a condition of equilibrium. At this time the animals occupy their situations horizontally, perhaps also vertically, from the nearest part of the lamp to the periphery according to the following orders (several actual examples are given below): — planktonic crustaceans — *Engraulis* of Shirasu stage — *Engraulis* of grown stages — Carangidae — *Sphyraena* (22h. 25 min. June 23, 1950), planktonic crustaceans — *Engraulis* of Shirasu stage — *Pempheris* — Carangidae — squids — (1h. 00 min. Aug. 6, 1950), planktonic crustaceans — *Stolephorus* — *Engraulis* of grown stages — *Pempheris* — Carangidae — *Sphyraena* (2h. 40 min. Aug. 6, 1950), planktonic crustaceans — *Engraulis* of Shirasu stage — *Stolephorus* — *Engraulis* of grown stages — *Sphyraena* (19h. 45 min. Aug. 11, 1950). The arrangement of the situation of the animals from the nearest part of the lamp to the periphery is quite parallel to the order mentioned previously. This arrangement is called the standard form, from which many modifications are derived by the dispersive activity of the higher predators. When higher predators are not so numerous or their predating activities are not so violent, the spatial relations of lamp-animals are not changed, except for the animals of the lowest rank of the community, which are unable to keep their positions and are driven away from the central part [*Stolephorus* — Carangidae — *Sphyraena* — benthonic fishes (vertically) or squids (horizontally) (4h. 05 min. June 24, 1950), *Engraulis* of grown stage — *Stolephorus* — benthonic fishes (vertically) or squids (horizontally) (4h. 10 min. Aug. 17, 1950), *Stolephorus* — *Pempheris* — Carangidae — benthonic fishes (vertically) or squids (horizontally) (0h. 00 min. Aug. 6, 1950), Carangidae — *Sphyraena* (vertically) or squids (horizontally) (23h. 05 min. Aug. 22, 1950)]. When the higher predators are numerous their predating activities become more violent, the spatial relations of animals in the community are reversed; the central part is occupied by animals of higher ranks[*Tylosurus* — Carangidae — *Pempheris* — *Engraulis* — squids (2h. 40 min. Aug. 23, 1950) and *Tylosurus* — Carangidae — *Stolephorus* (2h. 00 min. Aug. 24, 1950)]. Lastly comes the case when the predating is very violent. This time most animals are unable to approach the light, the community consists merely of the predators and

some much weaker animals quite indifferent to the food habits of the predators [planktonic crustaceans — Tetraodontidae — *Trichiurus* (19h. 20 min. Sept. 17, 1950), planktonic crustaceans — *Engraulis* of Shirasu stage — *Trichiurus* (3h. 25 min. Sept. 18, 1950)]. During the observations I have also recorded the order of arrival of main lamp-animals near the lamp. The order of animals, determined by the mode of frequency, is as follows: planktonic crustaceans — *Engraulis* of Shirasu stage — *Atherina* — *Cypselurus* — *Engraulis* — *Pempheris* — *Stolephorus* — *Sphyraena* — squids — Carangidae — *Trichiurus*. Squids contain some small individuals which come to the light early and are considered to belong to the prey group. The order of arrival of squids as solely the tertiary predators is much later. Although *Sphyraena* seems to come to the light earlier than carangids in the order determined by the mode of frequency: *Sphyraena* — squids — Carangidae — *Trichiurus*, in actual cases it and *Trichiurus* assemble to the light last. Whenever they visited the light relatively earlier, no other animals could be expected under the lamp after their arrival. Actually there was no case, in that the carangid came to the light later than squids, *Sphyraena* and *Trichiurus*. From these facts the order of arrival near the light may be determined as follows: Carangidae — *Sphyraena* — squids — *Trichiurus*. Thus, the order of arrival near the light is quite parallel to the order of food rank and the spatial arrangement mentioned previously.

Successional changes are strongly affected by the dispersing activity and the order of arrival; those two facts are also related closely with the rank of animals in the lamp-community described previously.

B. Predators absent.

At Murotsu, about 35 miles west of Kobe, the gray rock cods (*Sebastodes inermis*) are gathered by scattered bait and angled up in the daytime. At night, the acetylene lamp is placed near the rock not far from the coast and the fishes gather around the lamp to eat the zooplankton and Shirasu assembling around the lamp. Then fishermen angle for these fishes.

In the latter case, it has been said that the more preys are assembled around the lamp the more fishes are caught. The amount of conger leptocepharus in preys is considered one of the key factors. Actually the stomach of the angled gray rock cod is filled with the zooplankton and fry which are considered to be assembled to the lamp. I have been told that the fishes hardly assemble in the daytime near the rock where the lamp is put at night, even if scattered baits are placed in the water. It is clear that the prey plays a significant role and there are no predators of the fishes in the present case.

C. Preys absent.

As I have asserted the significance of the prey of the object fishes so strongly that readers may feel a contradiction in the title of this paragraph, there is a case lacking the prey of the object fishes in the community. It must be understood, however, that the light is used in previous cases to gather fishes in places where no fish is found in swarms. In this case, however, the light is used to attract the fishes in places where fishes are found in swarms.

In Harima nada, a part of the Inland sea west of Awazi Is., the shoals of *Engraulis* are easily recognized on winter nights by the glimmering light brought about on the sea-surface by swimming *Engraulis*. Fishing boats pursue the shoals and go across them, when the lamps are lighted. The fishes are scattered at first, but the shoals are soon reformed and keep the circular movement around the light. In this case, there is no influence of the lower ranks on the behavior of *Engraulis*, although there are some cases when the larger fishes such as yellow tails (*Seriola quinqueradiata*) appear and disperse the shoal formed around the lamp. It is not certain whether these higher predators are the fishes always swimming after the shoal before the lamp is lighted or fishes assembled after the lamp is lighted; although the former supposition seems more reasonable than the latter from the observations of *Engraulis* shoals in the day time.

D. Preys and predators absent.

At Ejima, about 10 miles SSW from Murotsu, *Engraulis* shoals rest at night among the rocks near the coast. These fishes assemble to the light when a light of relatively weak intensity moves slowly along the coast. In this case, the fishes assemble to the light so rapidly that no effect of preys can be considered. Also the influences of other fishes are not admitted, because the carangid and mackerel swim away to the outer sea and yellow tails can not approach near the coast. There are found some half-beaks (*Hyporhamphus sajori*) and flat-fishes (*Paralichthys olivaccus*) mixing in the *Engraulis* shoal caught among the fishes in this region by the light, but they are all of the indifferent group and scarcely have any influence upon the shoal of *Engraulis*.

After many types of social structures of lamp-communities have been discussed, it may be concluded that the mechanism keeping the fishes near the light is based on the two factors, light and food-relations, though these two factors are unable to be treated separately. There are some intermediate forms between the animals comprising prey animals and primary predators, whose behaviors near the lamp are primarily regulated by light, and the animals comprising quaternary and end predators, whose behaviors near the lamp are regulated by the

preys. These intermediate forms may be arranged as follows:—higher primary predators being regulated more strongly by light than by their preys—secondary predators being regulated by both factors almost equally—tertiary predators being regulated mainly by their preys, though being affected also by light in some degree. Thus the effect of the light differs considerably according to the situations of the object fishes in the ecosystem. The purse seining at Harima nada and the anchovy fisheries at Ejima are the extreme instances using the light to allure the fishes directly to the lamp by phototaxis; and the gray rock cod fisheries at Murotsu is an extreme example using the light to gather the preys of the object fishes.

The coactions in lamp-communities are strongly affected by the fish fauna, habits of animals and the environmental relations in the area; consequently they may be accepted as the reproduction of the coactions of these ecological factors, which are regulating the cosmos of the area spatially and at all times, and in a short time in a limiting area. Thus, the investigation of the lamp-communities seems appropriate to recommend as one of the most convenient methods of observing the coaction of animals in the natural condition in a certain area.

THE HAKE FISHERIES OFF THE WEST COAST OF CHILE

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Since 1945 there has occurred a tremendous development of the hake fishery in the Pacific along the coast of Chile. The catch of 1945 totalled only 11,000 tons, whereas in 1951 it was 44,000 tons or four times as big.

This big increase was mainly achieved through a change in the methods of fishing. Whereas formerly hake fishery was only carried out by Chilean fishermen working from small boats with nets or hooks, in later years German fishing vessels have been called in carrying out a modern fishery with trawls in order that the increased demand for hake by the fish meal plants could be met.

This intense trawl fishing, until then unknown in Chile, caused great concern not only among the Chilean fishermen, but also with the Chilean fishery authorities.

Therefore, when I for half a year in 1951–52 worked as a fishery expert in Chile, for FAO and the Chilean Government, I was asked to pay special attention to the fishery for hake, *Merluccius* (Spanish *Merluza* or *pescada*) and especially to provide for an assessment of the stock of hake, to investigate if there were reasons for fear of overfishing.

It was by then known that two species of hake occurred in Chilean waters, *Merluccius gayi* and *M. australis.* Their areas of distribution were however not known, nor was it known if one only or both species were affected by the newly established trawl fishery. In the following the term "hake" is used for *M. gayi* whereas the *M. australis* is named "southern hake."

The two species are very much alike. However, it was found that the number of gill rakers on the lower arm of the first gill arch was different, varying in the hake between 14–17 and in the southern hake between 9–10. No overlapping in numbers was found.

The experimental trawlings carried out showed that the hake was found only north of Corral and the southern hake only in the area south of Puerto Montt and in the southern archipelago. It is possible that a small overlapping of their areas occurs between Puerto Montt

and Corral. Only the hake is affected by the present trawl fishery, which is carried out between Coquimbo in the north and Talcahuano in the south.

Owing to the rocky nature of the Chilean continental shelf it is only in very small, minute areas of the large coastal region between Coquimbo and Talcahuano that trawling could be carried out. This fact alone makes it rather improbable that overfishing could occur through the present trawl fishery.

The hake was found from ca. 20 to ca. 150 m. depth and in greatest quantities between 50 and 150 m. In deeper waters deeper than 150 m., the trawl could not be operated. The fact that the catch was far smaller between 125–150 m. than between 50 and 125 m. shows, however, that greater concentrations of hake at the bottom in deeper water can hardly be expected.

The biological study of the hake carried out in connection with the experimental trawling showed the following main results:

Reproduction

The spawning season is very extended, lasting from the beginning of October to the end of April. The material further indicated that the long spawning season has two maxima, one bigger in October–January and a smaller in April–May.

The length upon attaining maturity for the first time varies somewhat from south to north. Fifty per cent were found mature in the southern area at a length of 37 cm, in the northern area already at 30 cm. The males grow mature at a somewhat smaller size than the females.

Growth

Owing to a great number of individuals with accessory rings in scales and otoliths, these gave only little help for the determination of growth. However, measurements of large numbers showed distinct peaks of the length curves and thus the length at the close of the first to fourth year could be determined as follows:

1 year old—16cm
2 years old—27cm
3 years old—38cm
4 years old—47cm

The growth of the females is only a little faster than that of the males, the 3-year old females being 3–4 cm bigger than the males. Further, the females grow to a far bigger size than the males, and probably live longer. No males bigger than 52 cm were found; females, however,

were found rather frequently right up to sizes of 80 cm. It must in this connection be borne in mind that the investigation only covered part of the area of distribution, and that the difference in size between the sexes in the material caught may be due to a different pattern of migrations for the older year classes of each sex.

Food and Feeding Habits

According to the stomach contents, the hake is mainly feeding on plankton animals; sardines, anchovies and various crustaceans. True bottom animals, as worms and molluscs, were hardly ever found in the stomachs.

In accordance with this feeding habit the hake undertakes diurnal vertical migrations following the same migrations of the food animals, shunning the upper layers of the sea during the day.

This habit of feeding on macro-plankton makes it possible for the hake to live independent of the bottom. In this connection it is of interest that bigger concentrations of hake can only be found on the trawling grounds along the coast from September to May (in the spawning season). Taking the feeding habits into consideration it is well possible that, apart from this period, the hake is living in the free water-layers either over the fishing grounds along the coast or farther seawards.

Regional Distribution According to Size

It was the general opinion that in order to protect the young hake, trawling should be prohibited in shallow coastal waters, and in fact large areas of shallow water along the coast were closed to trawlfishing. However, the investigations showed beyond doubt that the younger and smaller individuals lived in deeper water; in the shallow coastal water only large and medium-sized individuals were found. Thus for the protection of the growing hake, the prohibition of trawlfishing in shallow water was of no avail.

Migrations

For the assessment of stock and for an accurate determination of the probability of overfishing, a knowledge of the migrations is essential. The investigations showed the following pattern of migrations:

As the smallest (youngest) bottom stages are found far away from the shore, it is probable that the larvae live over this deeper water. The scarcity of spawning and spent females in the catches on the coastal fishing grounds indicates that part of the spawning is likely to occur over deeper water. The *first migration* of the merluza is a drift of eggs

or larvae out to deeper water. The second migration is the return of the young individuals in the course of 2 or 3 years to the coastal waters.

The third migration is a movement back again to deeper water for spawning. A fourth migration is the dispersal of the fish after spawning (observed through the trawlfishing). As the spawning shoals are made up of at least two or three groups, it is clear that these migrations occur annually.

However, the fact that the biggest individuals (larger than 60 cm.) are more numerous in deeper than in shallow water, shows that the older merluzas do not return to shallower water. It is also quite possible that the fact that males are not found in the samples to a length of more than 52 cm is not due to the fact that the males do not attain a larger size, but is caused by an earlier cessation of the shoreward migration than it is the case with the females.

These two points leave open the possibility or probability, that there are concentrations of bigger merluza both male and female in deeper waters still not touched by fishery, forming a reserve from whose spawning activity recruitment of the merluza stock will continue without danger from the fishery.

Finally we have the diurnal migrations of the merluza in search for food towards the bottom at dawn and away from the bottom at nightfall.

As far as assessment of stock is concerned, the investigations under review have shown that the hake occur in great quantities off the Chilean coast from Coquimbo in the north to south of Talcahuano, and that only small patches of this vast region are touched by the trawlfishing in its present state. Further, the study of the migration has shown (1) that for part of the year the hake is dispersed either in intermediate water layers far from the bottom or farther seawards where it is not fished upon and (2) that part of the spawning occurs in offcoastal regions where no trawlfishing is carried out.

These facts show that for the time being no danger of overfishing of the stock is present. The areas not fished upon and the concentrations of hake not touched by the fishery are so large that they constitute a big reserve of hake to be drawn upon for the recruitment of the stocks fished.

However, as a considerable expanding of trawlfishing for hake can be expected in Chilean waters, and out of the consideration that "prevention is better than cure"—and in question of conservation of fish stocks—far more easy than cure, it was recommended that certain mesh regulations should already now be introduced in order to protect the smaller and—from a commercial point of view—less valuable individuals.

In order to protect the Chilean fishery conducted by smaller craft with nets and lines, it was further recommended that trawlfishing should be prohibited in certain coastal areas especially fished in by these smaller craft.

The present ground trawlfishing for hake in Chilean waters is carried out only on the tiny patches of smooth bottom occurring in a few places over the whole area and at day time only when the sunlight causes the hake to concentrate at the bottom. The danger of overfishing of the hake through this fishery therefore hardly exists.

A real danger to the hake stock can, however, be expected the moment the modern midwater trawling is introduced in Chilean waters, making it possible for the fishing vessels to pursue the hake not only in the short periods when it is concentrated on the bottom but also during the diurnal migrations away from the bottom as well as during its seasonal migrations away from the coastal grounds, i.e. during the whole of its life.

In order to meet such a danger in the right way, a thorough knowledge of the biology of the hake is an absolute necessity. The report on the investigations therefore also contained a plan for further researches aiming at such a complete knowledge to form the basis for the judgement of what regulations of the fishery should and must be introduced in order to conserve the stock and maintain the fishery at its highest possible level.

REPORT ON THE ALGAE OF THE CHILEAN SEAS

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The purpose of this brief report is to present a picture of the Chilean algae flora, quoting its characteristic species, particularly those which can be used as raw material or food.

An ecological rather than a systematic approach has been followed. With regards to the commercially important algae the author has not gone into details about the techniques applied for their utilization.

The Chilean algae flora extends along the western coast of South America, from Lat. 18°22′ S. down to Cape Horn. Within the Chilean realm numerous islands are included. Important among them, because of their size, abundance of algae and available phycological literature are Juan Fernández, Desventuradas (San Félix and San Ambrosio) and Easter Island. In addition the Chilean Antarctic Region, limited by the meridians 53° W. and 90° W. and the South Pole, should be considered. The Chilean algae domain extends therefore from tropical latitudes down to the South polar region.

From Arica to Chiloé the biological and physico-chemical conditions (salinity, tides, temperature, light, physical nature of the substratum) are approximately uniform. From Chiloé to Cape Horn exist numerous archipelagos, rocky coasts, waters with low salt content and the greatest tide difference in Chile (up to 10 m.).

The Antarctic Region with high cliff characteristics, bottom deposits, temperature, salinity, marine currents, tides, ice, penetrations of light, etc. have a particular and specific influence on the phycological flora, characterized by endemisms and the abundance of calcareous algae.

This paper should deal only with the first two referred regions, in so much that the algae flora of the Antarctic has become well known since Foster, in 1829, collected in Graham's Land the first algae of the region.

The Marine Biological Station of the University of Chile, located at Montemar, have started a systematic and phytogeographic study of the algae of the Chilean territorial waters. In the last few years, some contributions on this subject, from the systematic and technical point

of view, have been published. Also the station has already assembled a well stocked collection including specimens from the Chilean mainland, its islands, and the Antarctic, as well as from various regions of other continents.

The region from Arica to Cape Horn is a very rich one, both in genera and species. There is a littoral rocky zone, beaten by the constant and strong wave impact, with deep and shallow pools, and a sublittoral zone where the rocks are cliff-like and covered by a veritable belt of large-sized algae.

The author does not attempt to make a systematic list of all the species, but will only refer to the most characteristic of the benthic *Chlorophyceae, Phaeophyceae,* and *Rhodophyceae* of the continental shelf.

Among the species so far identified, some are cosmopolitan, and, in the northern zone, there are elements common to the Peruvian flora. The islands are characterized by their endemicity. Some of the large *Phaeophyceae* species are also found in the waters off South Africa and New Zealand.

A. In the littoral zone we distinguish:

1. *An upper littoral belt,* characterized by algae resistant both to desiccation and to changes in salinity, particularly in the pools.

MYXOPHYCEAE

NOSTOCOCALES

Lyngbya confervoides C. A. Ag., on the rocks of the upper littoral belt.

CHLOROPHYCEAE

ULOTRICALES

Enteromorpha bulbosa (Suhr.) Kütz.
E. compressa (L.) Grev.
E. intestinalis (L.) Link.
E. Linza (L.) J. Ag.
Ulva lactuca (L.) v. *rigida* (Ag.) Le Jolis.
U. v. *latissima* D. C.

CLADOPHORALES

Chaetomorpha linum (Müller) Kütz.
Ch. aerea (Dilwyn)
Cladophora pacifica (Mont.) Kütz.
C. incompta Hook. f. et Harv.
C. subsimplex Kütz.
Spongomorpha arcta (Dilw.) Kütz.

PHAEOPHYCEAE

PUNCTARIALES

Scytosiphon lomentarius (Lyngby.) J. Ag.

RHODOPHYCEAE

BANGIALES

Bangia fuscopurpurea (Dilw.) Lyngby.
Porphyra columbina Mont.
P. f. *Kunthiana* Hamel.

2. *A middle littoral belt,* peculiar to sheltered beaches in which there is an abundance of *Phaeophyceae, Rhodophyceae* and some *Chlorophyceae.*

CHLOROPHYCEAE

SIPHONALES

Codium dimorphum Svedelius; forming a deep green velvet on vertical cliffs.

PHAEOPHYCEAE

DICTYOTALES

Padina Commersonii Bory.
Glossophara Kunthii (C. A. Ag.) J. Ag.

PUNCTARIALES

Ilea fascia (Müll.) Fr.
Colpomenia sinuosa (Roth.) Derb. et Sol.
Endarachne Binghamiae J. Ag.
Scytothamnus australis Hook. f. et Harv.
Adenocystis utricularis (Bory) Skottsb.

SPHACELARIALES

Halopteris hordacea (Harv.) Sauv.
H. funicularis (Mont.) Sauv.

ECTOCARPALES

Ectocarpus siliculosus (Dilw.) Lyngb.
Pylaiella littoralis (L.) Kjellm.

RHODOPHYCEAE

GELIDIALES

Gelidium crinale (Turn.) J. Ag.
G. filicinum Bory.
G. lingulatum J. Ag.

NEMALIONALES

Chaetangium variolosum (Mont.) J. Ag.

CRYPTONEMIALES

Grateloupia Cutleriae Binder
Callophyllis variegata (Bory) Kütz.

Corallina chilensis Decaisne.
Hildebrantia Le Cannellieri Hariot.

GIGARTINALES

Schyzymenia Binderi. J. Ag.
Plocamium pacificum Kylin.
Iridaea laminarioides Bory.
I. obovata Kütz.
Gigartina Chamissoi (C. A. Ag.) J. Ag.
G. Chauvinii J. Ag.
G. Lessonii (Bory) J. Ag.
G. Teedii (Roth.) Lamour.
Chondrus canaliculatus Grev.
Gracilaria lemanaeformis (Bory) Weber-van Bosse.
G. lichenoides (L.) Gmell.
Ahnfeltia Durvillaei (Bory) J. Ag.
Gymnogongrus furcellatus (C. Ag.) J. Ag.

CERAMIALES

Ceramium rubrum (Huds.) C. A. Ag.
C. Dozei Hariot.
Centroceras clavolatum (C. A. Ag.) Mont.
Polysiphonia alscissa Hook. f. et Harv.
Laurencia chilensis D. T. Forti et Howe
Heterosiphonia Berkeleyi Mont.

RHODYMENIALES

Dendrymenia flabellifolia (Bory Skottsb.)
Rhodymenia corallina (Bory)

3. *A. breakers* belt, with large *Phaeophyceae* and some *Rhodophyceae* belonging to the genera *Gelidium, Iridaea* and *Rhodymenia.* Among the *Phaeophyceae:*

Lessonia nigrescens Bory.
Macrocystis integrifolia Bory, and
Durvillaea antarctica (Cham.) Hariot.

B. In the sublittoral zone there are areas covered by large submerged *Phaeophyceae* belonging to the genera *Lessonia, Macrocystis* and *Durvillaea* and of the deep water *Rhodophyceae* with species of *Rhodymenia, Iridaea,* etc.

PHAEOPHYCEAE

FUCALES

Durvillaea antarctica (Cham.) Hariot.
D. Harveyi Hook. f. et Harv.

LAMINARIALES

Lessonia flavicans Bory.
L. nigrescens Bory.
Macrocystis integrifolia Bory.
M. pyrifera (L.) C. A. Ag.

DESMARESTIALES

Desmarestia herbacea (L.) Lamx.
D. Rossii Hook. f. et Harv.
D. Willii Reinsch.

Edible Algae

Some algae of the Chilean coast have been utilized from olden times in the feeding of man and animals. In the first place, it must be mentioned, the *Durvillaea antarctica* fucaceae, whose area extends from Valparaiso to the Antarctic region, is a very large alga with a strong discoidal holdfast, short and strong, cylindrical stipe, prolonged in a palmated frond, wedge-shaped at the base and branched at the top. The people utilize the laminar part of the thallus and stipe, known by the name of Ulte, Huilte or Coyofe. This alga is rich in iodine, contains about 5.88 mg. per 100 grs. of dried algae.

Under the name of Luche or Luchi the chlorophyceae, *Ulva lactuca*, and the rhodophyceae, *Porphyra columbina*, are consumed. They have the common characteristics of the laminar shape of the thallus and the curly edges. Both are rich in glucids, iodine and vitamins.

The rhodophyceae *Iridaea laminarioides*, commonly called Yapin, is used in Chiloé as pig fodder.

Cattle fodder is prepared in the central zone of Chile from species of *Macrocystis*.

In addition there are other species of marine algae susceptible of being utilized as human food or for fodder, belonging for example to the genera *Rhodymenia* and *Gigartina*, also utilized in other parts of the world.

The Algazos, name given to the algae cast up by the sea, are used in Chiloé as fertilizer for potato crops. They include species of the genera *Enteromorpha, Ulva,* and *Macrocystis*.

In the distant Easter Island, a Chilean possession, the natives eat the chlorophyceae, *Ulva lactuca* which they call Kiroke and also a species of *Dictyopteris,* a *Phaeophyceae* which they call Auke and consider delicious.

Industrial Algae

The Algae utilized for industrial purposes are members of the *Rhodophyceae* and *Phaeophyceae.*

Three years ago the industrial utilization of these species began for the production of phycocolloids, especially agar-agar. The species which have given best results belong to the genus *Gelidium* (*G. lingulatum* J. Ag. and *G. filicinum* Bory); they are found in southern Chile, from Antofagasta to Talcahuano under the tide line, in rocky places, where they are generally difficult to collect. Total yields vary between 11 and 23%.

Other Chilean agarophyte are: *Gracilaria* Greville, *Gigartina* Stockhouse, *Ahnfeltia* Fries, and *Gymnogongrus* Martius.

Good production has been obtained with *Gracilaria lemanaeformis* found from the Peruvian coast to the Island of Chiloé.

The Marine Biological Station of Montemar, with the purpose of cooperating in the industrial utilization of marine products, has investigated the problems relative to the extraction of agar, from different species of agarophyta algae inhabiting the coast and their chemical composition.

The agar extracted from the Chilean species as regards quality is equivalent to the best that can be imported; it is specially used in bacteriology and in the production of food commodities. It is also exported, principally to Argentina.

The large *Phaeophyceae* of the Chilean coast, which correspond to the Laminaria of Europe, belong to the genera *Lessonia, Durvillaea,* and *Macrocystis.* There is an incipient industry producing alginic acid, alkali-soluble ficocolloids, derived from poliuronic acid, at present in great demand for industrial, chemical and food purposes. The species tested in Montemar correspond to *Macrocystis pyrifera, M. integrifolia, Lessonia nigrescens,* and *L. flavicans* and *Durvillaea antarctica.*

All these algae grow in the breakers belt and in the sublittoral zone. They are partly uncovered during the low tide, which makes their harvesting easier, in spite of the rocky characteristics of the coast which prevents the use of mechanized techniques.

The abundance in Chile of those species can only be compared to that of Canada, Scotland and South Africa. Along the coast there are numerous and large beds of *Macrocystis,* which ensure the possibility of intensive exploitation.

The experiments carried out at the Montemar laboratory and at the Inveresk Institute (Scotland), by a number of the Station, give a 20 to 25% content of alginic acid for the mentioned species and very com-

mendable values for laminarin, manitol and fucoidin, all of which products are beginning to be in demand in the market.

The alginates industry disposes of abundant raw materials in Chile to serve as the basis for the preparation of a number of medical, chemical and food products.

On a small scale *Chondrus canaliculatus* (Ag.) Grev. instead *C. crispus* is used for extraction of carragenin, and *Macrocystis pyrifera, M. integrifolia* and *Lessonia flavicans* are used to produce kelp meal.

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THE FISHERIES OF CHILE

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Introduction

The coast of Chile extends from the tropics to near the Antarctic region for a length (not including islands and channels in the far south) of about 2900 miles, along the Southeast Pacific.

Chile is becoming aware of the wealth of her coastal waters. Increased action is being taken to utilize these natural resources to complement the food intake of the population and also to develop national brands for the domestic markets to replace formerly imported commodities and, in certain cases, for sale on the international market.

As in other Latin American countries where rapid progress is being made in the better utilization of their fishery resources, Chile is consistently showing an important increase in the output of its marine fisheries. From a total catch of about 30,600 metric tons in the prewar years, the production rose to 118,300 tons, or by about 386 per cent, in 1952. This is due particularly to the meat shortage and also to the encouragement of the fishing industry by both Government agencies and private interests.

Should the demand of the domestic market increase or new foreign markets be opened to Chilean fish and shellfish products, it is likely that a great deal of expansion could take place. Not only could fresh fish production be enlarged but processing would also become profitable for some valuable species.

1. Natural Conditions

Chile appears to possess all the natural advantages for the establishment of a very important fishing industry, perhaps the leading one in Latin America; a long and productive coast line, many valuable species of fish, molluscs and crustaceans, and a sea-going population which has been engaged in fishing for many years.

Favorable oceanographic conditions, particularly along the Humboldt current, are conducive to provision of varied marine species for commercial purposes, some of which are virtually unknown in most parts of the world.

The marine fauna of the Chilean coastal waters fall into two major biogeographical provinces. The northern section belongs to the temperate West South American or Peruvian-Chilean province, with its northern boundary at Agujas Point (Peru) and with its southern extreme in Chiloé Island, where the sub-Antarctic or Patagonian province begins.

The narrowness of the continental shelf confines the productive trawl fishery to limited areas between Quintero and Chiloé I., but the pelagic or high sea fisheries, virtually untapped, constitute invaluable potential resources.

Fish and shellfish are found in great abundance in Chilean waters and are so regularly available generally as to form a secure and sustained base for a greatly expanded one. Among the species represented are tuna (albacore and yellowfin), bonito, swordfish, sardines, herring and anchovies, cusk eel (the delicious "congrio"), mackerel, king crab, lobster, shrimp, oyster, etc. From these, products that are in constant demand in world markets may be derived. Some of the species mentioned —sardines and anchovies, e.g.—may be taken in mass production fishing at low cost for drying and salting to be marketed as a valuable food product which keeps well, is highly concentrated and can be easily distributed.

2. Labour and Equipment

a) *Fishermen.*

There are about 7500 men regularly engaged in fishing. The census of fishermen as of January 1950 gives 7229 fishermen operating all along the Chilean coast and 426 crewmen on fishing boats over 10 tons working for canneries; in the 1943 census the number of fishermen was given as 5517. In addition, the number of workmen in canneries and processing plants is 3816. In total, there are 11,471 men engaged in fishing and fish processing. In the Talcahuano region alone the number of the fishermen amounts to 2000.

The fishermen of Chile appear to form a homogeneous group. The great majority of them are hard working, enterprising, and intelligent. Because of these qualities they are capable of mastering new techniques. With expert instruction there is no doubt at all that they may be relied upon to develop increasing productivity. Surveys indicate that the chief problem among fishermen is lack of means to purchase adequate craft and gear. The average income of fishermen ranges from 1000 to 2000 pesos monthly, but individually might vary from about 500 to 8000 pesos (official rate: 1 American dollar = 110 Chilean pesos).

It is evident that with so low an income many fishermen do not earn their livings and are forced to devote part of their time to other jobs.

b) *Craft.*

In December 1951, out of a total of 4338 fishing craft used, approximately 64 were engine driven vessels of medium size (10 to 200 gross tons, including 12 whale catchers), 917 motorized small craft (most of them with portable gasoline engines), and 3357 open boats with oar and sail, representing 77 per cent of the total fishing fleet were in operation. The census taken in 1943 recorded 385 motorized and 2554 non-motorized vessels.

Almost all the present fishing fleet was built in Chilean yards from domestic materials and by local labor. Since the inception of the trawl fisheries in the early forties and the building of new processing plants, several large steel trawlers and some wooden purse seimers were imported, most of them from Belgium and Germany. The local shipyards have also been active in building new power-driven craft. Unfortunately some of these large boats have been wrecked or lost at sea.

Present types of boats appear to be adequate enough to supply the existent demand for fresh fish. However, due to the very low productivity per man and year of the small non-powered craft and the increased demand for raw material from the processing plants, both for canning and fish meal, if production costs are to be maintained at an adequate level, motorization of the fishing fleet is imperative and acquisition of larger and modern craft is necessary for fishing in distant grounds to supply fish varieties at lower price. Such boats could be built in Chilean shipyards if technical assistance is provided.

c) *Gear.*

The amount of fishing gear in Chile has been estimated in 1945 as including approximately 600 units of longlines ("palangre" or "espinel") used almost exclusively for cusk eel ("congrio"); about 400 gill nets ("amalladeras" or "trasmallo") of different types; about 1000 harpoons which account for practically the entire catch of swordfish; ring nets ("boliche") for bonito, sardine and anchovy, numbering 120; beach seines ("chinchorros de playa") of various types numbering about 250; otter trawl nets, exclusively used in the hake fishing; trolling lines for tuna fishing; lobster traps in Juan Fernandez Island; traps ("nasas") for crabs and shrimp, and about 200 diving outfits used in the shellfish fisheries.

While the longline is still of great importance for cusk eel, flounder and croaker fishing, the otter trawl has become of increasing importance in the recent years, in the fishing of hake or whiting, taking about 65% of the total fish catch.

Almost all the nets used in Chile are made from domestic materials and, although there is a lack of adequate fittings and cable, operations are fairly efficient.

d) *Investments.*

Chile's fishing industry was evaluated in June 1947 as representing an investment of approximately 400 million pesos, distributed as follows:

	Million pesos
Craft and gear	200
Processing plants	175
Fresh fish distributing and marketing facilities	10
Others	15
Total	400

It is probable that, on account of recent developments, particularly the severe inflation suffered by the country, the total investments in the industry are now 100% higher, that is around 800 million pesos.

3. Production

a) *The Fishing Zones.*

Chile can be roughly divided in respect of her marine fisheries, into five zones, which from north to south are:

North: Provinces of Tarapacá and Antofagasta
North Central: Province of Coquimbo
Central: Province of Valparaíso and San Antonio
South Central: Province of Talcahuano
South: Provinces of Valdivia and Puerto Montt.

The northern zone with Iquique, Antofagasta and Taltal, is important because of its pelagic fisheries which include such species as tuna, bonito, swordfish and pilchard, processed in the local canneries, the largest in the country.

The north central zone supplies the immediate mainland as well as the Santiago Market with the highest priced varieties of fresh fish, viz: cusk eel ("congrios negro" and "colorado"), flounder, croaker, mackerel, etc.

The central zone is the site of the large trawl fisheries centering in Valparaíso and San Antonio. Hake is the species exploited, with about 64 per cent of the catch going to fish meal plants.

The Talcahuano zone produces fresh fish, principally hake and cusk eel, with part of the catch sold locally and the balance being shipped by rail to Santiago; it also produces mackerel and sardine for local canneries.

In the southern zone fishing is mostly of the subsistence type, but being the richest in shellfish, these provinces contain most of the plants processing molluscs and crustaceans.

b) *The Catch.* (As indicated by Table I)

Fish landings have consistently increased since 1944. Figures for previous years, while showing an upward trend evidence some fluctuations. The rather spectacular increase in the fish catch is due to the development of the trawl fisheries for hake, offshore along the central section of the country (areas Valparaíso—San Antonio, and Talcahuano).

Shellfish landings manifest wider fluctuations than fish landings but there is also an apparent trend to rise during the past few years.

TABLE I

CHILE

FISH AND SHELLFISH LANDINGS, 1931 TO 1951
(*In Metric Tons*)

YEAR	FISH	SHELLFISH	TOTAL
1931	11,836	5,180	17,016
1932	14,204	8,982	23,186
1933	18,572	8,623	27,195
1934	17,680	8,207	25,887
1935	21,104	7,676	28,780
1936	27,579	7,282	34,861
1937	28,778	7,909	36,687
1938	24,114	6,458	30,572
1939	28,912	7,642	36,554
1940	27,094	11,216	38,310
1941	29,017	8,363	37,380
1942	24,086	8,128	32,214
1943	30,999	9,549	40,548
1944	29,023	10,778	39,801
1945	32,623	14,401	47,024
1946	39,815	21,128	60,943
1947	45,693	14,378	60,071
1948	47,396	17,328	64,724
1949	60,375	15,871	76,246
1950	69,337	17,529	86,866
1951	73,106	19,931	93,037
1952	94,370	23,916	118,286

Source: Dirección de Pesca y Caza, Ministerio de Economiá y Comercio, Chile.

In 1952, ten species (Table II) formed about 92 per cent of the total fish catch, with a single species, hake, accounting for more than 68 per cent of the total fish production.

c) *Disposal of the Catch.*

On the basis of the 1951 figures Table III has been prepared giving the utilization of the catch and for each item the weight of raw material and of the edible portion. The latter data are needed to estimate the *per caput* consumption.

There is a great spread in production *per capita*, from the lowest, 3 kilos in the southern zone of Puerto Montt, to 20–22 kilos in the northern districts. It shows that the production in the middle zones is not large enough to satisfy the demand of its large urban areas. In spite of the commerce between the zones which should help to distribute fish caught more equally according to the population, there seems to be big differences in fish available for domestic consumption between the various zones. The largest export of fresh fish takes place from the Talcahuano zone, from which a large proportion of its production of fresh fish is shipped, mainly to Santiago. This reduces quantities available for local consumption in this big fishery zone considerably. An influencing factor when considering fresh fish available for the domestic market is the season of the year. Taking the most important fish, Merluza is caught in only four months, from August to November, and 50% of Sierra in the four months from January to April. Since 50% of fish consumption is in fresh fish, it is obvious that, if consumption is to increase, consuming centres must have better storage and distribution facilities.

The Commercial Fisheries in all Latin America, but particularly in Chile, are generally slow to improve products or to develop new techniques, to exploit untapped resources, correct wasteful fishing methods or to utilize their raw materials with economical possibility. This backwardness is probably the consequence of the very diffused character of the fishing industry, ordinarily comprising small individual enterprises widely scattered along extensive coast lines and involving great diversity of local fisheries based on notoriously unstable supply.

4. Value of the Catch

The value of the catch in 1952 as paid to the fishermen has been estimated at 589 million pesos; 432 million for fish and 157 million for shellfish. Consumers paid around 1250 million pesos for fresh fish and shellfish and about 750 million for processed fish, making a total value paid by the consumers of about 1.52 billion pesos.

TABLE II

CHILE
FISH LANDINGS IN 1952

				METRIC TONS	PERCENTAGE OF FISH TOTAL CATCH
1.	Hake	Merluza o Pescada	*Merluccius gayi*	64.449	68.3
2. 3. 4.	Cusk Eels 3 spp.	Congrios negro, colorado y dorado	*Genypterus spp.*	5.124	5.4
5.	Bonito	Bonito	*Sarda chiliensis*	4.886	5.2
6.	Snake Mackerel	Sierra	*Thyrsites atun*	4.604	4.9
7.	Pilchard	Sardinas	*Sardinops sagax*	4.437	4.7
8.	Snook	Robalo	*Eleginops maclovinus*	1.591	1.7
9.	Jack	Jurel	*Trachurus murphyi*	1.341	1.4
10.	Croaker	Corvina	*Cilus montti*	1.204	1.3
	SUBTOTAL			87.636	92.9
	Other spp.			6.734	7.1
	TOTAL			94.370	100.0

Source: Basic data from the Dirección de Pesca y Caza, Ministerio de Economiá y Comercio, Chile.

TABLE III

CHILE

UTILIZATION OF THE CATCH IN 1951
(*In Metric Tons*)

	LANDINGS	PERCENTAGE	EDIBLE PORTION
	Fish		
Fresh, whole	36,680	50.2	19,774
Fresh, filets	316	0.4	136
Dried	337	0.5	88
Salted	35	0.1	5
Smoked	224	0.3	150
For meal	27,376	37.4	5,787 *
Canned	8,138	11.1	3,325
Total	73,106	100.0	29,265
	Shellfish		
Fresh	12,684	63.6	1,569
Canned	7,247	36.35	1,224
TOTAL	19,931	100.0	2,793
GRAND TOTAL	93,037		32,058

Source: Estimated from data collected by the Dirección de Pesca y Caza, Ministerio de Economiá y Comercio, Chile.

* Utilized in poultry and milk cow feeding.

Exports were valued in 1951 at about 45 million; imports of fish commodities were 3 million, and imported supplies and materials for the industry (not including the value of the large trawl vessels brought to Chile) an additional 25 million. It is estimated that the foreign exchange balance for the fishing industry is about 50 million pesos annually.

5. WHALING INDUSTRY

Two Chilean companies engage in whaling. The larger is the "Compañía Industrial" with its principal offices in Valparaíso; the other, which is quite small, the "Compañía Pesquera y Commercial de Macaya Hermanos", is established in San Vicente, Talcahuano.

The large firm has six whaling vessels and a shore station at Quintay, not far from Valparaíso. The whaling operations of this company were begun during the last war to provide substitute materials for tallow and other scarce fats in its manufacturing processes. In 1951, this company caught and processed 1096 whales (735 sperm whales, the balance being baleen whales, chiefly finback—Table IV).

TABLE IV

WHALES CAUGHT IN CHILE
1943 TO 1951

	1	2	3	4	5	6	7
YEAR	RIGHT WHALE	BLUE WHALE	FINBACK	HUMPBACK	SPERM WHALE	SEI WHALE	TOTAL
1943	1	1	13	—	128	—	143
1944	—	3	49	3	363	—	418
1945	—	41	65	11	366	—	483
1946	—	11	238	5	340	1	595
1947	—	22	90	15	720	2	849
1948	—	85	289	5	731	6	1,116
1949	—	18	209	3	680	—	991
1950	—	43	273	4	773	—	1,093
1951	—	77	279	3	735	2	1,096

1.—*Balaena australis*
2.—*Balaenoptera musculus*
3.—*Balaenoptera physalis*
4.—*Megaptera nodosa*
5.—*Physeter macrocephalus*
6.—*Balaenoptera borealis*

Source: Dirección de Pesca y Caza, Ministerio de Economiá y Comercio, Chile.

The baleen whales yielded 721 metric tons of oil and the sperm whales 2600 metric tons, a total oil production of 3321 metric tons for this company, whose whaling activities are an adjunct to its extensive and diversified soap and manufacturing activities. Over 90% of this concern's output is used in the manufacture of soaps, the remainder (baleen oil) goes into its production of margarine. The carcasses are used in the fish meal and bone meal manufacture.

The smaller company owns a catcher which operates along the central and southern Chilean coast. The 1949 production was 900 barrels (152.4 metric tons) of baleen whale oil and 2301 (84.8 metric tons) of sperm whale oil. When this firm at Talcahuano cannot sell its production to the Compañía Industrial for hydrogenation and use in the latter firm's soap factory, the Talcahuano firm sells its production to small soap factories located in the south of Chile.

6. PROCESSING INDUSTRIES

Fish have been processed in Chile for many years, but on a limited scale. During the past fifteen years, however, considerable activity has taken place. In 1950, 56 fish processing industries with a capital of 350 million pesos were in operation.

Refrigeration:

Although a number of refrigeration plants exist, these generally lack modern machinery and employ sub-standard methods. The role of refrigeration in the fishing industry is not yet thoroughly understood. Ice, chiefly because of the present high prices, is little used by the fishing industry. The proximity of the fish producing areas to the main markets does not seem to require the more expensive methods of preservation of fish, such as freezing.

Salteries:

Salting and drying of fish received considerable impetus during the last war, chiefly for export. Production costs have been high, and for this reason comparatively little salt fish is consumed in Chile. The so-called "bacalao de Juan Fernandez" (actually a grouper) is one of several species which is salted and dried. In addition, small amounts of hake, shark, elephant fish and cusk eel are dried; tuna, herring, sardine and anchovy salted; and swordfish, snake mackerel, herring, sardine, anchovy hake and smelt smoked. In 1951 about 375 tons of fish were dried and salted, and 224 tons smoked. The resultant products were 90 and 5 tons respectively.

Canneries:

Canning started in Chile around 1865. In 1946 there were some 20 canning plants having an approximate declared capital of 40 million Chilean pesos. By 1950 the number of fish canning concerns increased to 56 with an active capital of 350 million pesos. These canneries are scattered from Arica in the far north to the extreme south in Punta Arenas on the Strait of Magellan. The canneries are concentrated in the following areas: Tarapacá–Antofagasta, Valparaíso, Talcahuano, Puerto Montt, Calbuco, and Punta Arenas. From the standpoint of production the Tarapacá–Antofagasta areas and the Talcahuano area are the major centres of canned fish production, processing respectively 6,700 and 17,900 tons of raw material.

Exact statistics of Chile's canned fish are not available, but the total figures give an idea of the steady rise in production. In 1936, around 1000 tons net of canned fish and shellfish were produced; 1951 fish pack, chiefly sardines, tuna and herring, amounted to a net weight of about 3425 metric tons.

Pesquera Iquique, S.A., with fish-freezing plant, plenty of refrigerated storage and tuna and sardine canning, owns the most modern and best equipped fish plant in all Chile, located in Iquique. In addition, there are Sociedad Industrial Pesquera de Tarapaca (elaborating the renowned brand "Cavancha"), with plants in Iquique and Taltal; Jorge Cerda's plant "El Buen Gusto" in Arica; Sociedad Pesquera Industrial Pacifico, in Iquique; Compañia Industrial Pesquera and Mateo Zlatar's plants, in Antofagasta; Industrias Pesqueras Guayacan in Coquimbo; Sociedad Italo-Portuguesa "Sipol" in Valparaíso; Jorge Sarquis' Sociedad Pesquera "Qurbosa" Conservas y Productos Pesqueros S.A.; and Meekes and Saelzer in Talcahuano—San Vicente are the largest fish canneries in the country, whose combined output exceeds 75% of the entire canned fish production.

Shellfish canning is centered in the southern zone. In 1951 twenty canneries were in operation, of which eleven are located at Calbuco Island; another five farther south and the balance in Punta Arenas. Sixteen canneries produced in that year 106,650 cases with an average of 6,660 cases per cannery, the largest output of a single cannery being 18,000 cases of finished product. A standard case of canned shellfish contains 48 cans of 240 grams net each. The net output amounted to 1225 metric tons.

The present fish canning industry, with few exceptions, does not employ modern machinery for efficient production methods. Costs, therefore, are relatively high. Although buildings are usually good, equipment, layout, working space arrangements and labour saving devices are deficient. Machinery and other equipment, in general, are obsolete. Among the problems confronted by the Chilean fish processing industry, in common with other Latin American countries, are the difficulty of acquiring new equipment to replace obsolete machinery, the difficulty of obtaining foreign hard currency for cans, and the low standard of cans manufactured locally. In fact, containers are often made by the cannery and this practice has led to cans of sub-standard quality, a great divergence of sizes and added overhead expenses.

It is obvious that the Chilean canning industry with modernization and expansion will be capable of producing a much greater pack at lower costs than those prevailing at present. Increased production is dependent on the amount of tin plate available and of export markets to absorb the output. The most logical and readily available markets are those of other Latin American countries, but this outlet has not yet been utilized. United States importers maintain that high cost of transportation and difficulties of shipping make the venture of importing Chilean canned fish to the United States almost unprofitable. Moreover, production costs are at present abnormally high and Chilean canners are not in a position to capture any significant part of the world's market for commodities such as tuna and bonito. However, exports of canned fish and shellfish have risen from 112.4 metric tons in 1948 to 935.3 tons in 1951. It seems that the crustaceans and molluscs pack could find a good place in foreign markets.

Fish meal:

Annual production in two modern plants, one with a capacity of 10 tons per hour, located in San Antonio and several small or crude installations at the canneries, is estimated in 1951 at about 5,800 tons. The majority of the raw material used is hake obtained by trawling in the near fishing grounds. With a low oil content the hake is not

suitable for oil production. It appears that good possibilities exist for expansion of fish meal production both from wastes and from direct fishing. Nevertheless, the profitability of fish meal production in Chile by direct fishing remains to be seen. Cattle and poultry raising use almost all the domestic production of fish meal.

Fish oil:

Production of industrial fish oils in Chile is still very limited. Not more than 100 metric tons are estimated to be produced annually. However, this output is subject to increase as oil extraction proceeds in the fish meal plants already in operation and the new ones under construction.

Vitamined oils:

Assays of samples of fish liver from Chilean waters indicate that rich sources of vitamin "A" are available. Reported 1951 production, chiefly of low potency oils, was about 29,700 liters. Present output is in the neighborhood of 120 billion International Units, derived from about 275 tons of liver. Different species of shark and also tuna supplied the raw material.

7. Fresh Water Fish

The indigenous fish fauna of Chilean lakes and rivers is exceptionally poor, particularly regarding edible species. The once abundant smelt (pejerry — *Basilichthys microlepidotus*), native trout (trucha criolla — *Percichthys trucha*), and catfish (bagre de agus dulce — *Nematogenys inermis*), as well as the small farionelas or peladillas (*Haplochiton* spp.), were overfished in the measure that human settlements expanded, with the result that, at present, these species are on the verge of extinction.

Since 1905, the fisheries administration implemented an ambitious programme of restocking Chilean fresh waters with species such as the European salmon and trouts, the North American rainbow and steel head trouts and the Alaskan salmon. These activities were continued for a number of years and, with the exception of the European and the North American salmons which acclimatization apparently failed, the other species were successfully established. In more recent years this planting with foreign species was expanded to new areas and other species, such as the valuable Argentinean smelt (*Odonthestes bonariensis*), were introduced. It is interesting to report that all these acclimatized species grow in Chilean waters to a larger size than in the original countries. However, the utilization of these stocks is mainly for sportive purposes.

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PRELIMINARY LIST OF CHILEAN FISHES AND THEIR VERNACULAR NAMES

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The author has devoted six months, as an FAO Fisheries expert, surveying fishery potentialities along the Chilean coast. While this survey has been concentrated on commercially important species, during the trips made aboard fishing boats, a number of interesting species were caught and identified.

In this preliminary note some changes have been introduced regarding the nomenclature and taxonomic status of the species recorded in Chilean waters. This matter will be discussed in the author's final report to FAO.

On the basis of the existent recording literature and of my personal observations, a list has been compiled including all the species of fish, *sensu latu*, known to be resident in Chilean fresh water and coastal waters, and also those migrants that seasonally approach the littoral of the mainland, the off shore waters and the distant islands. The names marked with an asterisk refer to species identified by the writer.

For the sake of simplification the following notations are used:
N., C., and S. indicate respectively Northern, Central and Southern Sections of Chile.
JF refers to Juan Fernández Island.
SFA to San Felix and San Ambrosio Islands.
P to the Easter Island (Isla de Pascua).

I MORDACIIDAE

1. *Geotria australis* Gray — Lamprea, lamprea de bolsa. (C.S.)

II EPTARETIDAE

2. *Polistotrema polytrema* (Girard) (C.S.)
3. *Polistotrema decatrema* (Regan) (C.S.)

III MYXINIDAE

4. *Myxine tridentiger* Garman (C.S.)
5. *Myxine affinis* Günther (S.)

IV HEXANCHIDAE

6. *Hexanchus griseus* (Bonnaterre) Tiburón. (C.S.)
7. *Heptranchias perlo* (Bonnaterre) Tiburón. (C.)

V ISURIDAE

8.	*Isurus oxyrinchus* Rafinesque	(N.C.S.)
9.	*Lamna nasus* (Bonnaterre)	(C.S.)
10.	*Carcharodon carcharias* (Linnaeus)	Tiburón. (S.)

VI CETORHINIDAE

* 11.	*Cetorhinus maximus* (Gunner)	Tiburón gigante. (C.)

VII ALOPIDAE

12.	*Alopias vulpinus* (Bonnaterre)	Pez zorro. (N.C.S.)

VIII SCYLIORHINIDAE

13.	*Cephaloscyllium ventricosum* (Garman)	(Chile).
14.	*Halaelurus bivius* (Smith)	Pintarroja. (C.S.)
* 15.	*Halaelurus chilensis* (Guichenot)	Pintarroja. (N.C.S.)

IX TRIAENODONIDAE

* 16.	*Mustelus mento* Cope	Tollo. (N.C.S.JF)
* 17.	*Mustelus maculatus* (Kner y Steindachner)	Tollo. (N.)
18.	*Triaenodon nigricans* Philippi	(SFA)

X EULAMIIDAE

19.	*Galeorhinus chilensis* (Perez Canto)	Cazón. (C.S.)
* 20.	*Prionace glauca* (Linnaeus)	Azulejo. (N.C.S.)
21.	*Eulamia philippi* Fowler	(N.)
22.	*Eulamia robusta* (Philippi)	(N.S.)

XI SPHYRNIDAE

23.	*Sphyrna zygaena* (Linnaeus)	Pez Martillo. (N.)

XII SQUALIDAE

24.	*Scymnodon macracanthus* (Regan)	(S.)
25.	*Etmopterus paessleri* Lönnberg	(S.)
26.	*Etmopterus granulosus* (Günther)	(S.)
27.	*Squalus fernandezianus* Guichenot	Tollo. (C.S.JF)

XIII SQUATINIDAE

28.	*Squatina armata* (Philippi)	(N.C.S.)

XIV RHINOBATIDAE

29.	*Tarsistes philippi* Jordan	(N.C.S.)

XV RAJIDAE

30.	*Raja flavirostris* Philippi	Raya. (N.C.S.)
31.	*Raja magellanica* Steindachner	Raya. (S.)
32.	*Raja brachyurops* Fowler	Raya. (S.)
33.	*Psammobatis scobina* (Philippi)	Pequén. (N.C.S.)
34.	*Psammobatis lima* (Poeppig)	Trucha de mar. (N.C.S.)

XVI DASYATIDAE

35.	*Urotrygon chilensis* (Günther)	(Chile)
36.	*Urobatis marmoratus* (Philippi)	(C.)

XVII MYLIOBATIDAE

37. *Aetobatus peruvianus* (Garman) Aguila de mar. (N.)
38. *Rhinoptera chilensis* (Philippi) Aguila de mar. (N.)

XVIII MOBULIDAE

39. *Mobula tarapacana* (Philippi) (N.)

XIX TORPEDINIDAE

* 40. *Discopyge tschudii* Heckel Templadera. (N.C.S.)

XX CALLORYNCHIDAE

* 41. *Callorhinchus callorhinchus* (Linneaus) Peje Gallo. (N.C.S.)

XXI CLUPEIDAE

42. *Clupea fueguensis* Jenyns Sardina. (S.)
* 43. *Clupea bentincki* Norman Sardina, sardina anchoa. (C.S.)
* 44. *Spratella nov.* sp.? Sardina, sardina anchoa. (C.S.)
* 45. *Sardinops sagax sagax* (Jenyns) Sardina española. (N.C.)
* 46. *Ethmidium maculatum* (Valenciennes) Machuelo, machete. (N.C.)

XXII ENGRAULIDAE

* 47. *Engraulis ringens* Jenyns Sardina, sardina bocona, anchoveta, chicora. (N.C.S.)

XXIII APLOCHITONIDAE

48. *Aplochiton taeniatus* Jenyns Peladilla. (S.)
49. *Aplochiton zebra* Jenyns Peladilla. (S.)
50. *Aplochiton marinus* Eigenmann Peladilla. (S.)

XXIV STOMIATIDAE

51. *Stomias atriventer* Garman (Deep-sea).

XXV IDIACANTHIDAE

52. *Indiacanthus niger* Regan (Deep-sea).

XXVI GONOSTOMIDAE

53. *Cyclothone signata* Garman (Deep-sea).

XXVII MAUROLICIDAE

54. *Maurolicus mulleri* (Gmelin) (Deep-sea).

XXVIII GALAXIIDAE

55. *Brachygalaxias bullocki* (Regan) Puye. (S.)
56. *Galaxias attenuatus* (Jenyns) Puye. (S.)
57. *Galaxias gracillimus* (Canestrini) Puye. (S.)
58. *Galaxias maculatus* (Jenyns) Puye. (S.)
59. *Galaxias alpinus* (Jenyns) Puye. (S.)
60. *Galaxias globiceps* Eigenmann Puye. (S.)
61. *Galaxias platei* Steindachner Puye. (S.)

XXIX CHLOROPHTHALMIDAE

62. *Chlorophthalmus glacilis* Günther (JF)

XXX MYCTOPHIDAE

63. *Myctophum affine* (Lütken)	(Deep-sea).
64. *Myctophum tenisoni* Norman	(Deep-sea).
65. *Rhinoscopelus cocco* (Cocco)	(Deep-sea).

XXXI CHARACIDAE

66. *Cheirodon pisciculus* Girard	Pocha, pochita. (Freshwater).
67. *Cheirodon galusdae* Eigenmann	Pocha, pochita. (Freshwater).
68. *Cheirodon australe* Eigenmann	Pocha, pochita. (Freshwater).

XXXII DIPLOMYSTIDAE

69. *Diplomyste chilensis* (Molina)	Tollo, bagre de agua dulce. (Freshwater).

XXXIII ARIIDAE

70. *Netuma barbus* (Lacepede)	Bagre marino. (S.)

XXXIV PYGIDIDAE

71. *Hatcheria maldonadoi* Eigenmann	Bagre. (Freshwater).
72. *Hatcheria bullocki* Fowler	Bagre. (Freshwater).
73. *Hatcheria macraei* (Girard)	Bagre. (Freshwater).
74. *Pygidium chiltoni* Eigenmann	Bagre. (Freshwater).
75. *Pygidium areolatum* (Valenciennes)	Bagrecito. (Freshwater).
76. *Pygidium maculatum* (Valenciennes)	Bagre. (Freshwater).
77. *Nematogenys inermis* (Guichenot)	Bagre. (Freshwater).

XXXV LORICARIIDAE

78. *Ancistrus erinaceus* (Valenciennes)	(Freshwater).

XXXVI MURAENIDAE

79. *Muraena appendiculata* (Guichenot)	Murena, culebra de mar. (C.)
80. *Gymnothorax porphyreus* (Guichenot)	Murena, culebra de mar. (JF)
81. *Gymnothorax weineri* Sauvage	Murena, colebra de mar. (Chile).
82. *Gymnothorax chilensis* (Günther)	Murena, colebra de mar. (Chile).
83. *Gymnothorax modestus* (Kaup)	Murena, colebra de mar. (C.)

XXXVII OPHICHTHYIDAE

84. *Ophichthus ater* Peters	Anguila. (Chile).
85. *Ophichthus dicellurus* (Richardson)	Anguila. (N.C.)
86. *Ophichthus remiger* (Valenciennes)	Anguila. (C.)
87. *Ophichthus pacifici* (Günther)	Anguila. (N.C.)
88. *Ophichthus callaensis* (Günther)	Anguila. (N.C.)

XXXVIII CYEMIDAE

89. *Cyema atrum* Günther	(JF)

XXXIX NOTACANTHIDAE

90. *Gigliolia moseleyi* Goode y Bean (Deep-sea).

XL SCOMBERESOCIDAE

* 91. *Scomberesox equirostrum* Le Sueur Agujilla, punto fijo. (C.JF)

XLI HEMIRAMPHIDAE

92. *Hemiramphus phurcatus* Philippi Pez aguja. (P.)

XLII EXOCOETIDAE

93. *Exocoetus volitans* Linnaeus Pez volador. (N.)
94. *Cypsilurus lineatus* (Valenciennes) Pez volador. (JF)

XLIII MURAENOLEPIDAE

95. *Muraenolepsis orangiensis* Vaillant (S.)
96. *Muraenolepsis microps* Lönnberg (S.)

XLIV GADIDAE

97. *Saliota australis* (Günther) (S.)
98. *Physiculus marginatus* (Günther) (S.)
99. *Lotella fernandeziana* Rendahl (JF)
100. *Laemonema multiradiatum* (Thompson) (Deep-sea).
* 101. *Merluccius gayi* (Guichenot) Pescada, merluza (C.S.)
102. *Merluccius australis* (Hutton) Pescada, merluza. (S.)
103. *Macruronus magellanicus* Lönnberg Merluza de cola. (S.)
104. *Macruronus novae-zelandiae* (Hector) Merluza de cola. (S.)

XLV CORYPHAENOIDIDAE Granaderos

105. *Coryphaenoides holotrachys* (Günther) (Deep-sea).
106. *Coryphaenoides ariommus* Gilbert y Thompson (Deep-sea).
107. *Coryphaenoides ariommus* (Günther) (Deep-sea).
108. *Celorhynchus fasciatus* (Günther) (Deep-sea).
109. *Celorhynchus chilensis* Gilbert y Thompson (Deep-sea).
110. *Celorhynchus patagoniae* Gilbert y Thompson (Deep-sea).
111. *Macruroplus pudens* (Gilbert y Thompson) (Deep-sea).

XLVI MACRORHAMPHOSIDAE

112. *Macrorhamphosus fernandezianus* (Delfin) (JF)

XLVII SYNGNATHIDAE

113. *Syngnathus scicularis* Jenyns Aguja de mar. (N.C.S.)
114. *Syngnathus pelagicus* Linnaeus Aguja aguja de mar. (S.)
115. *Leptonotus blainvillianus* (Eydoux Gervais) Aguja de mar. (C.S.)

XLVIII CYPRINODONTIDAE

116. *Orestias agassizi* Valenciennes (N.Freshwater).

XLIX TRACHIPTERIDAE

117.	*Trachipterus altivelis* Kner	(C.S.)

L TRACHICHTHYIDAE

118.	*Trachichthys fernandezianus* Günther	(JF)

LI MUGILIDAE

119.	*Mugil cephalus* Linnaeus	Liza. (N.C.S.JF)
120.	*Mugil curima* Cuvier y Valenciennes	Liza. (N.)

LII ATHERINIDAE

* 121.	*Notocheirus hubbsi* Clark	(C.)
122.	*Basilichyhys australis* Eigenmann	Pejerrey. (Freshwater).
123.	*Basilichyhys microlepidotus* (Jenyns)	Pejerrey. (Freshwater).
124.	*Basilichyhys gracilis* (Steindachner)	Pejerrey. (JF)
125.	*Odontesthes mauleanum* (Steindachner)	Pejerrey. (Freshwater).
126.	*Odontesthes wiebrichi* Eigenmann	Pejerrey. (Freshwater).
127.	*Odontesthes itatanum* (Steindachner)	Pejerrey. (Freshwater).
128.	*Odontesthes brevianalis* (Günther)	Pejerrey. (Freshwater).
129.	*Odontesthes laticlavia* (Valenciennes)	Pejerrey. (Freshwater).
130.	*Odontesthes smitti* (Lahille)	Pejerrey. (S.)
131.	*Odontesthes nigricans* (Richardson)	Pejerrey. (S.)
132.	*Odontesthes regia* (Humboldt)	Pejerrey. (N.C.S.)

LIII SERRANIDAE

133.	*Percichthys trucha* (Valenciennes)	Trucha, perca trucha. (Freshwater).
134.	*Percichthys melanops* Girard	Trucha, perca trucha. (Freshwater).
135.	*Percilla gillissi* Girard	Carmelita. (Freshwater).
136.	*Percilla irwini* Eigenmann	Carmelita. (Freshwater).
137.	*Acanthistius pictus* (Tschudi)	(N.C.)
138.	*Gilbertia semicincta* (Valenciennes)	Cabrilla listada. (JF)
139.	*Hemelutjanus macropthalmos* Tschudi	Ojo de uva, papaniagua. (N.)
140.	*Polyprion oxygeneios* (Schneider)	Bacalao. (JF, SFA)
* 141.	*Paralabrax humeralis* (Valenciennes)	Cabrilla. (N.C.S.JF)
142.	*Paralabrax semifasciatus*	
143.	*Prionodes huascarii* (Steindachner)	(Chile)
144.	*Diplectrum conceptione* (Valenciennes)	(S.JF)
145.	*Caprodon longimanus* (Günther)	(JF)
146.	*Hemanthias peruanus* (Steindachner)	(Chile)
147.	*Callanthias platei* Steindachner	(JF)

LIV BRANCHIOSTEGIDAE

148.	*Prolatilus jugularis* (Valenciennes)	Blanquillo. (N.C.S.)
* 149.	*Caulolatilus princeps* (Jenyns)	(Chile)

LV POMATOMIDAE

150.	*Pomatomus saltatrix* (Linnaeus)	(C.)

LVI RACHYCENTRIDAE

151.	*Rachycentrodon canadum* (Linnaeus)	(JF)

LVII CARANGIDAE

152.	*Seriola mazatlana* (Steindachner)	(JF)
153.	*Seriola dorsalis* (Gill)	(N.)
* 154.	*Neptomenus crassus* Starks	Conjinoba. (N.)
* 155.	*Trachurus murphyi* Nichols	Jurel, furel. (N.C.S.JF)
156.	*Caranx georgianus* Valenciennes	Palometa, pampanito. (JF)
157.	*Parona signata* (Jenyns)	(S.)
158.	*Lichia albacora* Guichenot	Albacora. (C.S.)
159.	*Trachinotus paitensis* Cuvier y Valenciennes	(C.)

LVIII LEPIDOTIDAE

* 160.	*Lepidotus chilensis* (Guichenot)	(C.)

LIX CORYPHAENIDAE

161.	*Coryphaena hippurus* Linnaeus	Dorado. (N.)

LX EMMELICHTHYIDAE

162.	*Emmelichthys cyanescens* (Guichenot)	(C.)

LXI SCIAENIDAE

163.	*Cynoscion analis* (Jenyns)	Allanque. (N.C.)
164.	*Sciaena gilberti* Abbott	Corvinilla. (N.C.S.)
165.	*Sciaena deliciosa* (Tschudi)	Corvinilla. (N.)
166.	*Sciaena fasciata* (Tschudi)	Corvinilla. (N.C.)
167.	*Sciaena reedi* (Günther)	(JF)
168.	*Sciaena imberbis* (Günther)	(N.C.JF)
169.	*Micropogon furnieri* (Desmarest)	Corvina. (N.C.JF)
170.	*Stellifer minor* (Tschudi)	Corvinilla. (N.C.)
171.	*Menticirrhus ophiocephalus* (Jenyns)	Pichiguen. (N.JF)

LXII POMADASYIDAE

172.	*Pomadasys bipunctatus* Kner	(N)
* 173.	*Isacia conceptionis* (Cuvier)	Cabinza. (C.N.)
174.	*Cilus monti* Delfin	Corvina. (N.C.S.)
175.	*Anisotremus scapularis* (Tschudi)	Sargo. (N.)

LXIII SCORPIDAE

176.	*Scorpis chilensis* (Guichenot)	Pampanito. (JF)

LXIV GIRELLIDAE

177.	*Girella albostriata* Steindachner	Jeringuilla. (JF)
178.	*Girella foliciana* Clark	(SF)
* 179.	*Doydimodon laevifrons* (Tschudi)	Baunco. (N.)

LXV HISTIOPTERIDAE

180.	*Pentaceros kneri* Steindachner	(S.)

LXVI OPLEGNATHIDAE

181.	*Oplegnathus insignis* (Kner)	Loro. (N.)

LXVII APLODACTYLIDAE

* 182.	*Aplodactylus punctatus* Valenciennes	Jerguilla. (C.N.)
183.	*Aplodactylus vermiculatus* Valenciennes	Jerguilla. (C.)
184.	*Aplodactylus guttatus* Valenciennes	Jerguilla. (JF)

LXVIII POMACENTRIDAE

185.	*Chromis crusma* (Valenciennes)	Castañeta, burrito, pampanito, frailecillo. (N.C.S.)
186.	*Abudefduf saxatilis* (Linnaeus)	(N.)
187.	*Nexilosus latifrons* (Tschudi)	Castañeta, pampanito. (N.)

LXIX LABRIDAE

188.	*Pimelometopon maculatus* (Perez)	Peje perro, vieja colorada. (N.C.S.)
* 189.	*Pimelometopon darwini* (Jenyns)	Peje perro, pejeperro. (N.)
190.	*Bodianus diplotaenia* (Gill)	(N.)
191.	*Pseudolabrus gayi* (Valenciennes)	(JF)
192.	*Graus nigra* Philippi	Vieja, vieja negra. (C.N.)
193.	*Malapterus reticulatus* Valenciennes	Biya. (JF)

LXX CHEILODACTYLIDAE

194.	*Cheilodactylus gayi* (Kner)	Breca. (S.JF)
195.	*Cheilodactylus variegatus* (Valenciennes)	Pintadita, pintadilla. (N.C.)
196.	*Cheilodactylus antoni* (Valenciennes)	Bilagai. (C.)
197.	*Cheilodactylus bicornis* (Steindachner)	(JF)

LXXI LATRIDAE

198.	*Mendosoma lineata* Guichenot	Trompetero, trompero. (C.)
199.	*Mendosoma caerulescens* Guichenot	Cabinza. (C.)
200.	*Mendosoma fernandezianum* Guichenot	Cabinza. (C.)
201.	*Latris hecateia* Richardson	(S.)

LXXII MUGILOIDIDAE

* 202.	*Mugiloides chilensis* (Molina)	Robalo, rollizo. (N.C.S.)
203.	*Parapercis chilensis* Norman	(S.)

LXXIII TRACHINIDAE

204.	*Trachinus cornutus* Valenciennes	(N.)

LXXIV BOVICTIDAE

205.	*Bovictus chilensis* Regan	Torito. (C.S.JF)
206.	*Cottoperca govio* (Günther)	(S.)

LXXV NOTOTHENIDAE

207.	*Notothenia brevicauda* Lönnberg	(S.)
208.	*Notothenia canina* Smitt	(S.)
209.	*Notothenia cornucola* Richardson	(S.)
210.	*Notothenia elegans* Günther	(S.)
211.	*Notothenia jordani* Thompson	(S.)
212.	*Notothenia longipes* Steindachner	(S.)

213.	*Notothenia macrocephala* Günther	(C.S.)
214.	*Notothenia microlepidota* Hutton	(S.)
215.	*Notothenia sima* Richardson	(S.)
216.	*Notothenia squamiceps* Peters	(S.)
217.	*Notothenia tessellata* Richardson	(S.)
218.	*Notothenia wiltoni* Regan	(S.)
219.	*Dissostichus eleginoides* Smitt	(S.)
220.	*Eleginops maclovinus* (Valenciennes)	Robalo, robalito, robalo de piedra. (C.S.)
221.	*Harpagifer bispinis* (Schneider)	(S.)

LXXVI BLENNIDAE

222.	*Salarias chilensis* Clark	(C.)
223.	*Salarias viridis* Valenciennes	Borracho, torito. (N.C.)
224.	*Salarias rubro-punctatus* Valenciennes	Torito. (C.JF)
225.	*Salarias petersoni* (Fowler)	Torito. (N.)
226.	*Salarias variolatus* Valenciennes	(JF)
227.	*Scartichthys gigas* (Steindachner)	Torito, borracho, sueño. (N.C.)
228.	*Scartichthys concolor* (Philippi)	Torito. (C.)
229.	*Scartichthys modestus* (Philippi)	Torito. (C.)
230.	*Scartichthys eques* (Steindachner)	Torito. (N.C.S.)

LXXVII CLINIDAE

231.	*Auchenionchus crinitus* (Jenyns)	Tramboyo. (N.)
232.	*Auchenionchus variolonis* (Valenciennes)	Tramboyo. (N.C.S.)
233.	*Calliclinus geni-guttatus* (Valenciennes)	Vieja, tomoyo, tramboyo. (C.S.)
234.	*Myxodes foncki* (Philippi)	Doncella. (S.)
235.	*Myxodes viridis* (Valenciennes)	Doncella. (N.C.S.)
236.	*Myxodes cristatus* Valenciennes	Doncella. (C.)
237.	*Lepisoma philippii* (Steindachner)	Trombollo, tomoyo, vieja. (N.)
238.	*Labrisomus microcirrhis* (Valenciennes)	Trombollo, tomoyo, vieja. (C.)
239.	*Labrisomus niger* (Philippi)	(Chile)
240.	*Labrisomus conventryi* (Fowler)	Trombollo, tomoyo, vieja. (C.)
241.	*Labrisomus fernandezianus* (Guichenot)	Tromobollo, tomoyo, vieja. (JF)
242.	*Labrisomus guttulatus* (Valenciennes)	Trombollo, tomoyo, vieja. (C.S.)
243.	*Petroscirtes biocellatus* (Valenciennes)	Torito. (C.)
244.	*Petroscirtes fasciatus* (Jenyns)	Torito. (C.S.)

LXXVIII CHAENNICHTHYIDAE

245.	*Champsocephalus esox* (Günther)	(S.)

LXXIX ZOARCIDAE

246. *Ophthalmolycus macrops* (Günther) (S.)
247. *Iluocoetes fimbriatus* Jenyns (S.)
248. *Iluocoetes elongatus* (Smitt) (S.)
249. *Austrolycus depressiceps* (Regan) (S.)
250. *Austrolycus laticinctus* (Berg) (S.)
251. *Phucocoetes latitans* Jenyns (S.)
252. *Crossostomus chilensis* (Regan) (S.)
253. *Crossostomus fasciatus* (Lönnberg) (S.)
254. *Platea insignis* Steindachner (S.)
255. *Maynea puncta* (Jenyns) (S.)
256. *Maynea patagonica* Cunningham (S.)
257. *Melanostigma gelatinosum* Günther (S.)

LXXX LYCODAPODIDAE

258. *Lycodapus australis* Norman (S.)
259. *Gymnelis pictus* (Günther) (S.)

LXXXI BROTULIDAE

260. *Cataetryx messieri* (Günther) (S.)

LXXXII OPHIDIIDAE

261. *Genypterus blacodes* (Schneider) Abadejo. (S.)
* 262. *Genypterus chilensis* (Guichenot) Congrio colorado, colorao. (N.C.S.)
* 263. *Genypterus maculatus* (Tschudi) Congrio negro, mono. (N.C.S.)

LXXXIII GEMPYLIDAE

* 264. *Thyrsites atun* (Euphrasen) Sierra. (C.S.)
265. *Thyrsitops lepidopodes* (Cuvier) Sierra. (S.)

LXXXIV SCOMBRIDAE

* 266. *Pneumatophorus peruanus* Jordan y Hubbe Caballa. (N.C.)

LXXXV THUNNIDAE

* 267. *Thunnus thynnus saliens* Jordan y Evermann Cimarrón. (C.)
* 268. *Germo alalunga* (Bonnaterre) Atún, atún de aleta larga. (N.C.S.)
* 269. *Neothunnus macropterus* (Schlegel) Atún, atún de aleta amarilla. (N.)
* 270. *Katsuwonus pelamis* (Linnaeus) Cachurreta. (N.)

LXXXVI CYBIIDAE

* 271. *Sarda chilensis* (Cuvier) Bonito o mono. (N.C.S.)

LXXXVII ISTIOPHORIDAE

272. *Makaira audax* (Philippi) Pez aguja. (N.C.S.)

LXXXVIII XIPHIIDAE

* 273. *Xiphias gladius* Linnaeus Albacore. (N.C.S.)

LXXXIX STROMATEIDAE

* 274.	*Stromateus maculatus* Cuvier y Valenciennes	Pampanito. (JF)

XC CENTROLOPHIDAE

275.	*Palinurichthys caeruleus* (Guichenot)	Pampanito. (JF)
276.	*Leirus peruanus* (Steindachner)	(N.)

XCI NOMEIDAE

277.	*Seriolella porosa* Guichenot	Cojinoba, casinova, hachita. (N.C.S.)
278.	*Seriolella violacea* Guichenot	Cojinoba, casinova, hachita. (C.)

XCII GOBIIDAE

279.	*Gobius chiloensis* Guichenot	(S.)
280.	*Gobiosoma ophiocephalum* (Jenyns)	(S.JF)

XCIII SCORPAENIDAE

281.	*Sebastodes oculatus* (Cuvier)	Cabrilla, cabrilla española. (N.C.S.)
282.	*Sebastodes prognathus* Tortonese	(C.)
283.	*Sebastodes darwini* (Cramer)	Cabrilla. (N.C.S.)
284.	*Sebastodes chilensis* Steindachner	Vieja colorada, cabrilla. (C.S.)
285.	*Helicolenus lengerichi* Norman	(JF.)
286.	*Scorpaena thomsoni* Günther	Peje diablo. (JF)
287.	*Scorpaena fernandeziana* Steindachner	Peje diablo. (JF)
288.	*Scorpaena histrio* Jenyns	¡Peje diablo. (JF)

XCIV TRIGLIDAE

289.	*Trigla guttata* Philippi	(JF)
290.	*Cheilidonichthys pictus* (Günther)	(JF)

XCV CONGRIOPODIDAE

291.	*Congriopus peruvianus* (Cuvier y Valenciennes)	Peje chancho, chanchito. (N.C.S.)
292.	*Agriopus hispidus* (Jenyns)	Chanchito, peje chancho. (S.)

XCVI COTTIDAE
(Including NORMANICHTHYIDAE)

* 293.	*Normanichthys crokeri* Clark	Mote, cochinilla. (C.S.)

XCVII PSYCHROLUTIDAE
(=NEOPHRYNICHTHYIDAE)

294.	*Neophrynichthys marmoratus* Gill	(S.)

XCVIII AGONIDAE

295.	*Agonopsis chiloensis* (Jenyns)	(C.S.)

XCIX CICLOPTERIDAE
(Including LIPARIDAE and LIPAROPIDAE)

296. *Cyclopterichthys amissus* Vaillant (S.)
297. *Careproctus falklandica* (Lönnberg) (S.)
298. *Careproctus pallidus* (Vaillant) (S.)

C SCOPHTHAIMIDAE

299. *Thysanopsetta nareri* Günther
Lenguado. (S.)
300. *Hippoglossina macrops* Steindachner
Lenguado. (C.S.)
301. *Hippoglossina mystacium* Ginsburg
Lenguado. (S.)
302. *Paralichthys adspersus* (Steindachner)
Lenguado. (N.C.JF)
303. *Paralichthys fernandezianus* Steindachner Lenguado. (JF)
304. *Paralichthys patagonicus* Jordan
Lenguado. (S.)
305. *Paralichthys hilgendorfi* Steindachner
Lenguado. (JF)
306. *Paralichthys microps* Günther)
Lenguado. (N.C.S.)
307. *Paralichthys schmitti* Ginsburg
Lenguado. (JF)
308. *Paralichthys coeruleostica* Steindachner Lenguado. (JF)

CI ECHENEIDAE

309. *Remora remora* (Linnaeus) Piloto, remora. (N.C.S.)

CII DIODONTIDAE

310. *Diodon hystrix* (Linnaeus) Erizo. (P.)

CIII MOLIDAE

311. *Mola mola* (Linnaeus) Peje luna, peje sol. (C.S.)

CIV GOBIESOCIDAE

312. *Sicyases sanguineus* Müller y Troschel Peje sapo. (C.N.JF.)
313. *Sicyogaster marmoratus* (Jenyns) Peje sapo. (S.)

CV BATRACHOIDIDAE

* 314. *Aphos porosus* (Valenciennes) Peje bagre. (N.C.S.)

For the preparation of this list of Chilean fishes, different papers were consulted, Guichenot's in Gay, Philippi, Perez Canto, Delfin and others; but particularly we have been guided by Fowler's catalogue, published in the years 1941 to 1943 in the "Revista Chilena de Historia Natural." The families have been arranged according to Berg's classification (1940). The fresh water species have been checked with Eigen-

mann's study published by the U.S. National Academy of Sciences (Vol. XXII, Report II), modifying the generic denominations of the *Atherinidae* according to our own judgment. We have kept in mind for the north of Chile the similar fish fauna of Perú, as described in Hildebrand's paper (*U.S. Nat. Mus. Bull.* 189, 1946), and for the Southern part of the country, Norman's paper in the Discovery Reports (vol. XVI, 1937).

During our assignment in Chile (15 February to 15 August 1953), we continued the work started by Dr. Erick M. Poulsen, FAO expert, who concentrated on the biology of bottom fishes, especially the hake (two species of *Merluccius*). We have paid special attention to pelagic species, of seasonal abundance in the fishing grounds, including representatives of the Thunnidae, Cybiidae, Xiphiidae, Engraulidae and Clupeidae.

At the time of our survey, all the Thunnidae approached the Chilean coast in search of food, with their gonads inactive. *Neothunnus macropterus,* which appears off the coasts of the provinces of Tarapacá and Antofagasta comes in through oceanic waters, feeding then principally on pelagic crustaceans, and soon invades the green coastal waters in search of *Engraulis;* this fishery is the basis of a coming industry, and in years of abundance a catch of about 1,000 tons is obtained, although in poor years the catch diminishes to only 50 tons a year. *Germo alalunga,* called *Germo germo* by some authors, is the tuna of central Chile, which in small groups can reach Talcahuano and is also frequent along the northern zone. It may be missing some years, but even with the present primitive fishing gear, up to 500 tons a year can be caught. Albacore is used for fresh fish consumption, either directly or frozen, or for canning.

We had the opportunity to examine some specimens of what we have called *Thunnus thynnus saliens* in view of the small differences observed compared with Atlantic tuna. Its scarcity is due principally to the gear employed, which is the same used to catch albacore, and which do not stand the strain of very big specimens.

The only Cybiidae of Chile, *Sarda chilensis,* with a catch of nearly 5,000 tons, approaches the north coast to spawn, generally in cold green water; in July specimens with very developed gonads are found.

The swordfish, inhabitant of warm, blue, oceanic waters, is of great economic importance, as up to 2,000 tons per year can be caught off the northern coast. It appears also at times in the Valparaíso area reaching as far south as Talcahuano.

We have only been able to find one Engraulidae in Chilean waters (*Engraulis rengens*), of which we studied more than 1,000 specimens.

This anchovy is of great interest, not only from the industrial point of view, but also because it is the primary food supply of many species of fish. Thunnidae and Cybiidae in the northern coast feed on anchovy. Its schools are prayed upon by other species of larger size and also by the guano birds (*Pelecanus occidentalis thagus, sula variegata, Phalacrocorax bougainvilli*) and marine mammals (*Otaria byronia*). It is also used for bait by the fishermen.

Among the Clupeids the most important is the sardine, which we have called *Sardinops sagax sagax,* to separate it as a mere subspecies of the *Sardinops sagax caerulea* of California. The Chilean sardine is abundant in the northern coast, principally in the Antofagasta zone.

EDIBLE SHELLFISH OF THE CHILEAN COAST

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In 20 years shellfish production of Chile has risen from 5,180 tons in 1931 to 19,931 tons in 1951, the largest increases being recorded in 1940 and 1946. The zones of Puerto Montt, Talcahuano, Valparaíso, and Antofagasta are the most important producing areas for edible crustaceans and molluscs. Puerto Montt produces almost 80% of all shellfish consumed in the country; 46% of its local production is used for canning and in this form distributed all over the country.

However, as exemplified by the CHORO (*Choromytilus chorus* Molina, 1782), the production of some species has steadily declined. In fact, its catch decreased during the period 1930–1943 from 3,237 to 1,651 tons. This calls for the immediate adoption of conservation measures. On the other hand, from 1945 to 1951, the total production of OYSTERS (*Ostrea chilensis* Philippi, 1845) has mounted from 260 to 598 tons or more than double. This increase is due to enforced conservation practices and to annual restocking of depleted beds.

The most sought after species of shellfish, from the industrial point of view are: LANGOSTINOS (Plated lobsters), ALMEJAS (Clams), CALAMARES (Squids), CENTOLLAS (King crabs), CHOLGAS (Mussels), CHORITOS (Horse-mussels), ERIZOS (Sea urchins), TACAS (Hard clams), PICOS (Giant acorn-shells), PIURES (Edible sea-squirts), APANCORAS and CANGREJOS (Crabs), on which information will be given later on.

In 1951 the amount of shellfish used for canning was 7,244,061 Kg. with a net yield, on an edible basis, of 1,223,921 Kg. The consumption of fresh shellfish during the same year reached a total of 12,684,405 Kg. with a net yield of 1,569,100 Kg.

Echinodermata

Loxechinus albus (Molina, 1782). ERIZO COLORADO o ERIZO COMESTIBLE (Red or Edible Sea Urchin). Among the echinoderms of Chile the only one of commercial value and preferably consumed fresh. The gonads, commonly called lenguas de erizo (sea urchin tongues), are canned in oil, mostly in small plants located at the Island of Calbuco. In addition, along the coast from Callao, Perú, to the Magel-

lanic province, it is consumed fresh in great quantities wherever abundant.

Crustacea

Lithodes antarcticus (Hombron et Jacquinot, 1853). CENTOLLA (King crab). A crustacean much sought after for processing due to the quality and good taste of its flesh. The catch during 1950 and 1951 has decreased considerably, being of 61 and 55 tons respectively, while in years of abundance (1946) it amounted to 126 tons. Its area of distribution on the Chilean coast extends from Puerto Montt to the Strait of Magellan. It has also been found in the deep waters of the coast of Buenos Aires, Argentina. The fishing grounds in Chile are in the region of Calbuco, Quellón, Aysen, southern canals, and the Strait of Magellan; in the Republic of Argentina it is caught in Ushuaia, in the Beagle canal, but production in that country is lower than in Chile (43 tons in 1938), (Carcelles, 1946). It is fished in shallow waters during the season when it approaches the beaches. It is sold canned in oil, but its fresh consumption is also considerable, though not recorded statistically (Schwabe, 1939 and 1941).

Jasus lalendei frontalis (Milne Edwards, 1837). LANGOSTA DE JUAN FERNANDEZ (Spiny lobster) found in the Archipelago of Juan Fernández and the Desventuradas Island (San Ambrosio and San Félix), (Holthuis, 1951). Because of its economic importance and the great domestic and foreign demand from Argentina, where it is also sent by air, unsuccessful attempts have been made to acclimatize this species in the Chilean mainland coast (Albert, 1898). Production registered between 1945 and 1951 shows the lowest catch in 1946 (56 tons) and the highest in 1948 (106 tons).

Balanus (*Megabalanus*) *psittacus* (Molina, 1782). PICO DE MAR or PICOROCO (Giant acorn-shell) in the region of Chiloé. Its wide area of distribution extends from Pascamayo (Perú) to the Strait of Magellan. Principal processing centres are Calbuco and Puerto Montt. The most important crustacean for industrial purposes, canned "au naturel" and in oil, and also in great demand for fresh consumption. Its catch amounted in 1945 to 307 tons and increased in 1951 to 407 tons.

LANGOSTINOS (Plated lobsters). This name is given in Chile to three species: *Munida gregaria* Leach, *Pleuroncodes monodon* Milne Edwards, and *Cervimunida johni* Porter, 1903. They are canned in jelly, mostly in the Valparaíso zone. In 1951, 19 tons were processed.

APANCORAS (Crabs). Statistics on shellfish production compiled by the Chilean Department of Fish and Game (Hernández, 1953) include under this item all species of JAIBAS (Crabs) consumed in Chile,

of which the most utilized are: *Cancer polyodon* Poeppig, 1836 and *C. plebejus* Poeppig, 1836 (JAIBA PELUDA); *Homalaspis plana* Milne Edwards, 1834 (JAIBA MORA or MORADA); *Ovalipes punctatus* De Haan, 1833 and *Taliepus dentatus* Milne Edwards, 1834 (PANCHOTE). The aggregate catch was over 300 tons between 1945 and 1949, but declined in 1949, to increase in 1951 to 623 tons.

CAMARON DE MAR (Prawn), *Rhynchocinetes typus* Milne Edwards, 1837. Of wide distribution; found in Chile, Perú, New Zealand, and Indian Ocean. In Chile its production has decreased from 83 in 1947 to 16 tons in 1951, Valparaíso being one of the most important producing centres.

Tunicata

PIURE or PIVRE (Sea-squirt), *Pyura chilensis* Molina, 1782 (Van Name, 1945) of wide distribution, from the Peruvian port of Mollendo (17°S) in the North to Chiloé Is. (about 42°S). It lives in shallow waters and is caught mostly for fresh consumption. Some factories in Calbuco can it "au naturel." It is an irregular oval shaped tunicate growing in very close groups, each individual independent with its own cuticular test. Its test and internal organs are consumed fresh or smoked; industrial utilization is negligible. In 1948, 235 tons were caught, but production has considerably diminished and in 1951 was only 91 tons.

Mollusca

CEPHALOPODA

CALAMAR (Squid), *Loligo gahi* D'Orbigny, 1835. Small cephalopoda about 10 cm. long consumed canned in oil. Although its area of distribution is extensive, including the biogeographical Peruvian and Patagonian provinces of South America, it is only processed in Calbuco with a net production of 1,111 Kg. in 1951. It is also used as fishing bait.

PULPO (Octopus), *Polypus fontaineanus* D'Orbigny, 1835. Inhabitant of the Chilean and Peruvian coasts; of a vivid red colour with granulated body surface. The maximum length observed is about 25 cms. Its arms are eaten, but it is not processed and is captured in small quantities.

JIBIA (Cuttlefish), *Dosidicus gigas* D'Orbigny, 1835. Big nocturnal cephalopoda usually beached in great quantities at Ritoque, Reñaca, Constitución and Talcahuano; utilized as fishing bait for cusk eel (*Genypterus* sp.).

GASTROPODA

LOCO, *Concholepas concholepas* Brug. 1789. Gastropoda of economic importance attaining great size; 33 tons were utilized in 1951 and canned in three ways: in oil, special brand, and "au naturel." It is hand picked in the intertidal zone or by divers with or without diving equipment. The principal fishing centres are Los Vilos, Quintero, Valparaíso and Puerto Montt. The mollusc's powerful foot is consumed tenderized by beating together with salt or with sawdust before cooking. It is processed in the region of Calbuco and Puerto Montt.

Other gastropods of popular demand are:

CARACOL GRANDE DE ESPUELA (Chorus), *Chorus giganteus* Less., 1829. Found originally in Concepción; its area of distribution extends up to the bay of Valparaíso (Riveros-Zúñiga, 1950); caught in traps baited with fish or crustacean wastes; eaten cooked; taste resembling that of *Concholepas concholepas.*

CARACOLES (Top-shells). Under this name are consumed some edible species of the genera *Tegula,* such as *T. atra* Less., 1830, the MELONHUE of the Chiloé zone; *T. tridentata* Potiez et Michaud, 1838; *T. quadricostata* Gray, 1838; *Acanthina calcar* Martyn (Unicorn-shell), 1784 and *Turbo* (*Prisogaster*) *niger* (Turbine-shell) Wood, 1828, known as LILIHUEN. Not processed, but sought after by the fishermen to be eaten cooked.

Fissurella (Keyhole limpets). Abundant gastropods whose tasteful foot is frequently consumed fresh. Also called CHAPAS or CHAPES. The most used species are *F. maxima* Sow., 1834; *F. picta* Lamk, 1822; *F. crassa* Lamk, 1822; *F. limbata* Sow., 1834; *F. latemarginata* Sow., 1834; (Riveros-Zúñiga, 1951). Area of distribution generally very extensive. Abundant in the intertidal zone on the bare rocks or on those covered by algae.

Patella, Nacella, Scurria, Siphonaria (Limpets) are genera whose species are sought as food and called LAPAS, a name which is applied in general to mollusks with conical shell which adhere strongly to the rocks or other supports. Some species utilized are *Patella magellanica* Gmelin, 1791; *Nacella clypeater* Less., 1830; *Scurria scurra* Less., 1830; and *Siphonaria* (*Liriola*) *lessoni* Blainville, 1824.

Thais chocolata Duclos, 1832, (Thais) is found from Paita in Perú, where it is called CARACOL, to Valparaíso. In Coquimbo and vicinity it is known as LOCATE or LOCA because of its resemblance in taste to the *Concholepas concholepas.* Fished by divers and very well liked.

PIQUILHUE (Volutes) *Adelomelon magellanicus* Lamk, 1811 and *A. ancilla* Sow., 1786, are the species consumed in the region of Chiloé.

AMPHINEURA

Chiton and *Tonicia* (Chitons) are genera of *Polyplacophora* with some species found in the market. In a number of Chilean ports they are sold under the name of COGOTES, but they find little acceptance.

PELECYPODA

From the industrial point of view, the following families are of importance, (by order of value): *Mytilidae, Ostreidae, Mesodesmatidae, Veneridae* and *Pectenidae.*

Among the *Mytilidae* the total volume of production in 1945 was 9,950 tons and 12,289 in 1951, the highest production being in 1946 with 15,082 tons. The catch of the most valuable species has diminished a great deal due to uncontrolled and extensive exploitation, leading to the extraction of very young specimens, to the evident danger of the conservation of the species. The fishing methods, which literally collect every specimen from the beds, have had a depleting effect shown in the disappearance of the beds nearest to the factories; therefore it has been necessary to search for them in more distant places.

To the new genus *Choromytilus* (Soot-Ryen, 1952) belongs *C. chorus* (Molina, 1782) CHORO (Giant mussel) with area of distribution from Pascamayo (Perú) to Orange Bay (Chile). Its uncontrolled exploitation continued for decades has caused depletion and there is urgent need of protecting the species. It is the biggest of the marine choros and is greatly esteemed from the nutritive point of view. It adheres to its supports through a strong byssus and has a big oval oblong shell, bluish in colour, covered by a blackish periostracum.

Mytilus ater Molina, 1782, *Aulacomya magellanica* Chemnitz, 1819 (Carcelles, 1942), and *M. chilensis* Hupé, 1854, are commonly called CHOLGAS (Mussels). The first has a smooth surface and is found from Manta (Ecuador) to Talcahuano; the second abundant in Magallanes but is found north up to Valparaíso, and the last along an extended area from Callao (Perú) to Tierra del Fuego, Falkland Is., and the coast off Buenos Aires. The total production of CHOLGAS is around 4,000 to 7,000 tons. They are usually consumed fresh or smoked. In 1951 canned production amounted to 2,900 tons, "au naturel," special brand, and in oil. The Puerto Montt zone (Calbuco, Puerto Aguirre, Quellón, Aulén, San Rafael) industrializes the greatest quota of cholgas. *M. chilensis,* called CHILEAN or SOUTHERN MEJILLON, is caught in Tierra del Fuego, Patagonia and Strait of Magellan. *Aulacomya magellanica* Chemnitz, is the GRAN MEJILLON OF MAGALLANES (Magellanic large mussel) or CHORO or MEJILLON RAYADO.

Modiolus dayctiliformis Hupé, is characterized by its oblong shape, smoothed at the umbo and by the brownish green periostracum; the inside of the shell is nacreous tinged with violet. The CHORITO or QUILMAHUE (Horse-mussel) is found from Antofagasta to the Chiloé zone, but only consumed by fishermen.

Brachydontes purpuratus Lamk, 1797 is the CHORITO MAICO (Purple horse-mussel) found along all the Chilean coast, Tierra del Fuego, Falkland Is., and Argentine coast up to Golfo Nuevo, also called MEJILLON DEL SUR or MEJILLON PURPURA. It is fished in all its area, but not for industrial purposes.

Ostrea chilensis Philippi, 1845, the OSTRA CHILENA (Oyster) found in an extended area from the coast of California to the zone of Chiloé. It is the most demanded mollusk. Its exploitation has increased since 1945 from 260 tons to 598 tons in 1951, Ancud being the zone of greatest production. This production comes principally from artificially stocked beds and has been helped by timely restrictions.

Pecten (*Plagioctenum*) *purpuratus* Lamk, 1819, OSTION is the Chilean scallop most in demand, with orbicular, convex shell, with 26 ribs and pinkish white colour. The adductor muscle has a delicious flavour and is preferably consumed fresh. In 1945, 65 tons, in 1950, 387 tons, and in 1951 only 262 tons were extracted.

Chlamys patagonicus King, 1831, OSTION MAGALLANICO (Magellanic scallop). Very common in the coasts of the Strait of Magellan and in the fjords up to Puerto Montt, but not of great economic value.

Protothaca thaca Molina, 1782, TACA (Hard clam) is found from Ancón (Perú) to the Chonos Archipelago and is in demand because of its excellent taste to be consumed baked on embers or in soups or "curantos" (primitive preparation of shellfish and algae, cooked in ground holes with hot stones). Production in 1950 and 1951 has amounted to 901 and 913 tons respectively.

Mesodesma donacium Lamk, 1818, MACHA (Soft shell clam), is found from Chiloé to the Sechura Bay, in Perú. Maximum production amounted to 668 tons in 1951. Its white shell is covered by a straw yellow periostracum and of its ends the shortest is subtruncate and the widest, compressed and channelled. Obtained in great quantities in Las Ventanas of Quintero, Iloca, etc.

Tagelus (*Mesopleura*) *dombeyi* Lamk, 1818, is one of the NAVAJAS DE MAR (Razor-clams), found from Tumbes, Perú, to the Chiloé Is. Hinged with two inconspicuous cardinal teeth; consumed by the coastal people and frequently found in southern markets where its local name is QUIVI.

Solen gaudichaudi Chemn, 1843, and *Ensis macha* Molina, 1782, are called NAVAJUELAS DE MAR (Razor-shells). The first is found in a small area, from Valparaíso to Coquimbo, and the second, from Valparaíso to Magallanes up to the Atlantic coast, reaching the Gulf of San Matías (Carcelles, 1950). Both are sand species found at great depths and collected at low tide.

Pholas (*Thovana*) *chilensis* Molina, 1782, commonly called COMES (Piddock) is found from the Gulf of Panamá to the Chiloé Is. Considered one of the best shellfish and known by its two anterior plates with anterior-central nuclei, a small and transversial middle plate and a long and narrow posterior plate. No lines in the third posterior of the shell.

Mulinia bicolor Gray, 1837; *M. edulis* King, 1831, and *M. byronensis* Gray, 1838, species which because of their resemblance to the TACAS (Hard clams) are called TAQUILLAS (Small hard clams). Their areas of distribution are extensive: *M. edulis* is found from Callao to the Strait of Magellan, *M. byronensis* from Salaverry (Perú) to the Strait of Magellan, *M. bicolor* from Copiapó to Valparaíso. (Some authors consider *M. bicolor* Gray synonymous with *M. edulis*). They are frequently found in the markets of a number of sea ports in Chile.

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NOTES ON THE COMMERCIALLY IMPORTANT FISHES OF CHILE

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The fish fauna of the coast of Chile, which extends from the border of Peru (18°22′S) to Cape Horn (56°S), is constituted of coastal species typical of the Chilean district, generally understood to be the region between the latitudes of Valdivia (39°45′S) and Tocopilla (22°41′S). Among these species are also found northern and southern fishes from the Peruvian and Magellanic districts. Besides these species, other pelagic ones are also found which migrate to the south through the outer waters of the Coastal Current of Peru following, during their transgresses and regresses, the tropical and subtropical oceanic waters.

The transgression of these waters, at a temperature and salinity of about 15° and 35‰, respectively, starts approximately in October, reaches its maximum in February and its minimum in August, when they move away from the coast, between Tocopilla and the province of Cautin, a short distance north of Valdivia.

At the time of the regression of the warm waters, the cold waters, with temperatures around 12°C, which during the summer do not surpass the latitude of the peninsula of Taitao (46°30′S), extend towards the north on a narrow coastal strip reaching as far as 32°S, a little north of the site of the Marine Biological Station of Montemar (Estación de Biologia Marina de Montemar), (32°51′24″S), located in the Bay of Valparaíso.

The analysis of the observations made in the Marine Biological Station since 1947, shows that the surface temperature of the sea water fluctuated in February between 14° and 16°C; in August between 11° and 12°C, and in October, between 12° and 13°C. Occasionally there has been a maximum of 18°C in February and a minimum of around 9°C in August.

Thanks to the indicated facts, the Marine Biological Station is located in the most favourable point of the Chilean coast regarding ichthyological observations. The majority of the species characteristic of the Magellanic and Peruvian districts reach the latitude of the Station in question. Of the 50 species of commercial importance considered below, only 7 were not caught in the neighbourhood of

the Station, which is a small number compared with the 16 species missing in the waters of Talcahuano (36°44′S), and 12 in the waters of Antofagasta (23°38′S).

The annual changes of temperature of the surface waters on the coast of Chile, besides determining the characteristics of the fish fauna and the migrations of many of the species of fish, also establish a typical annual cycle of plankton. Two distinct periods are found in the abundance of plankton; the rich Spring period, which extends until the beginning of Summer, and the poor Autumn period until the commencement of Winter. In July and August there are also two short periods of abundance and scarcity respectively (P. Yañez—Información preliminar sobre el ciclo anual de plancton superficial en la Bahía de Valparaíso ("Preliminary notes on the annual cycle of the surface plankton of the Bay of Valparaíso"), *Rev. Biol. Mar.* I, *1*, pp. 57–59).

Around one fifth of the 260 coastal and pelagic species (*Selachii* and *Teleostomi*), listed for the Chilean coast up to date (Henry W. Fowler—Fishes of Chile. *Rev. Chilena de Hist. Nat.* Santiago, Chile. 1943), are used as food by the inhabitants of the country. However, not more than twenty, in view of the volume of the catch and industrial value, are of real commercial importance.

A list of the species of fish of commercial value follows.

It is arranged systematically. Between brackets, following the scientific name, is given the common denomination of the species mostly utilized in the country, followed by the annual catch in tons, taken from Moises Hernández Ponce—Informaciónes estadísticas sobre la Pesca (Statistical Information on the Fisheries) Valparaíso, Chile. 1953.

CLASS *PISCES*
SUB-CLASS *ELASMOBRANCHII*
ORDER *SQUALIFORMS*
Family *Squalidae*

1.—*Squalus fernandinus* Mol., 1782. Small size species found in the water off the island of Juan Fernández and in the continental coast of Chile, from Valparaíso southwards. It has been extensively fished until recently because of its liver, which is very rich in vitamin oil.

ORDER *LAMNIFORMS*
Family *Carcharidae*

2.—*Mustelus mento* (Cope, 1877) (TOLLO; 800 tons) Species of medium size. Found from the Gulf of Arauco to Perú; mainly caught between Caldera and Coquimbo. It has excellent flesh, which is consumed fresh, dry, salted or smoked.

ORDER *CHIMAERIFORMS*
Family *Callorhynchidae*

3.—*Callorhynchus callorhynchus* (L.) (PEJEGALLO; 300 tons). Found along the whole coast. Its flesh is very much appreciated salted or smoked.

SUB-CLASS *TELEOSTOMI*
ORDER *CLUPEIFORMS*
Sub-order *CLUPEOIDEI*
Family *Clupeidae*

4.—*Ethmidium maculatum* (Val., 1847) (MACHUELO; 800 tons). It is the largest Chilean clupeid (length 35 cms.); it is caught from the Gulf of Arauco northwards and it is consumed smoked or canned.

5.—*Clupea fuegensis* (Jen., 1842), (sardina comun)

6.—*Sardinops sagax* (Jen., 1842), (cardina española)

7.—*Engraulis ringens* (Jen., 1842), (anchoa)

The first species is found from Valparaíso southwards, and the others, from the Gulf of Arauco northwards. Their catch amounts to 8000 tons annually, and they are mostly canned; however, they are also used for the manufacture of fish meal.

ORDER *GADIFORMS*
Family *Gadidae*

8.—*Merluccius gayi* (Guich., 1848), (PESCADA; 40,000 tons). Is the most important species for human consumption. Inhabits the waters from Caldera southwards; however, it is mainly caught between Valparaíso and Talcahuano for fresh fish consumption and manufacture of fish meal.

ORDER *PLEURONECTIFORMS*
Family *Bathidae*

9.—*Paralichthys microps* (Gthr., 1881).

10.—*P. adspersus* (Steind., 1867).

11.—*Hippoglossina macrops* (Steind., 1876).

These species are commonly known by the name of LENGUADO; their meat is of good quality and is consumed fresh; however, their catch is only about 400 tons yearly.

ORDER *PERCIFORMS*
Sub-order *PERCOIDEI*
Family *Malacanthidae* (=*Latilidae*)

12.—*Prolatilus jugularis* (Val., 1833), (BLANQUILLO; 400 tons). Inhabitant of the waters between Chiloé and Antofagasta. Consumed fresh, but it is not a very well liked fish.

Family *Carangidae*

13.—*Trachurus trachurus* (L.), (JUREL; 600 tons). Pelagic, cosmopolitan, tropical or sub-tropical; approaches the coast during the Summer, from Chiloé northwards, pursuing in large shoals, the sardines and anchovies.

Family *Pomadasyidae*

14.—*Cilus montti* (Delfín, 1900), (CORVINA; 1000 tons). Found from Chiloé to Tarapaca; abundant mostly during Spring and Summer.

15.—*Isacia conceptionis* (Cuv., 1830), (CABINZA; 400 tons). From the Gulf of Arauco northwards; like the previous species, is more abundant in the Spring and Summer.

16.—*Pomadasys schyvi* (Steind., 1902), RONCADOR.

17.—*Anisotremus scapularis* (Tschudi, 1843), (SARGO).

Family *Sciaenidae*

18.—*Sciaena deliciosa* (Tschudi, 1845), (AYANQUE).

These three later species come from Peru; they are caught from Antofagasta northwards, and are very popular.

19.—*Menticirrhus ophicephalus* (Jen., 1842), (*PICHIGUEN*).

20.—*Micropogon furnieri* (Desm., 1823).

These two species are caught in small quantities; are consumed fresh and are very much liked in their restricted area of distribution, which extends from Valparaíso to Chañaral.

Family *Labridae*

21.—*Pimelometopon maculatus* (Perez-Canto, 1886), (PEJE-PERRO). Gulf of Arauco to Iquique; consumed fresh.

22.—*Pimelometopon darwini* (Jen., 1842), (MULATO). From Antofagasta northwards. It is mostly caught in Tarapaca and is consumed fresh.

23.—*Graus nigra* (Philippi, 1887), (VIEJA). Very much esteemed for fresh consumption in its limited area of distribution, which extends from Coquimbo (30°S) to Colchagua (34°S).

Family *Aplodactylidae*

24.—*Aplodactylus punctatus* (Cuv. et Val., 1831), (JERGUILLA). Found in the area between the Gulf of Arauco and Perú. It is a fish about 35 cms. long, very little appreciated and consumed almost only by the fishermen.

Family *Cheilodactylidae*

25.—*Cheilodactylus variegatus* (Cuv. et Val., 1835), (PINTADILLA).

26.—*C. antonii* (Val. 1833), (BILAGAY). Fish of medium size and bright colors, characteristic of the coastal water from Valparaíso

northwards. The fishermen like it in view of the good quality of its flesh; however, it is caught only in small quantities.

Family *Notothenidae*

27.—*Eleginops maclovinus* (Val., 1830), (ROBALO; 2000 tons). Found from Tierra del Fuego to Valparaíso. Inhabits the waters along the beaches and enters in the river estuaries; it is the fish of Magellanic origin of greatest commercial value; abundant all year round in its original area, offering possibilities for canning. It is presently consumed fresh, salted and smoked.

Sub-Order *BLENNIOIDEI*
Family *Clinidae*

28.—*Calliclinus geniguttatus* (Val., 1836), (TOMOLLO; 25 tons). Magellan to Antofagasta. It is of average size; inhabits shallow waters in rocky beaches; its flesh is of good quality and is consumed fresh.

Family *Mugiloididae*

29.—*Mugiloides chilensis* (Mol., 1782), (ROLLIZO). Found from Magellan to Perú; grows up to 80 cms., and has a thick body and good quality flesh.

30.—*Auchenionchus variolosus* (Val., 1836), (TRAMBOLLO). Found from Tierra del Fuego to Iquique; very much alike the previous species in its aspect and quality.

Sub-Order *OPHIDIOIDEI*
Family *Ophidiidae*

31.—*Genypterus chilensis* (Guich., 1848), (CONGRIO COLORADO; 1500 tons). Found from Tierra del Fuego to Perú; it is the most liked fish in the central region of Chile; fished all year round and consumed fresh like the other following species. Inhabitant of rocky bottoms.

32.—*G. blacodes* (Schn., 1801), (CONGRIO NEGRO; 2000 tons). Found from Antofagasta to Tierra del Fuego; very much like the above species, but less appreciated as food. Its fishery has diminished in latter years.

33.—*G. maculatus* (Tschudi, 1846), (CONGRIO DORADO; 400 tons). It has been caught for six years only in a canyon of the continental shelf near Talcahuano.

Sub-Order *SCOMBROIDEI*
Family *Gempylidae*

34.—*Thyrsites atun* (Euphr., 1791).

35.—*Thyrsitops lepidopodes* (Cuv., 1830).

These two species are very much alike, and are known by the common name of SIERRA; they are pelagic fish which reach the coast in great quantities, from Coquimbo southwards during the Summer months. They are of very good quality and are consumed fresh and smoked. Maintain a considerable fishery (5000 tons).

Family *Scombridae*

36.—*Thunnus macropterus* (Schleg., 1850), (ATUN DE ALETA AMARILLA; 2000 tons). It is caught all year round from Tocopilla northwards, outside of the coastal current. It is tinned in the canneries of Iquique.

37.—*Germo alalunga* (Bonnat., 1788), (ATUN DE ALETA LARGA; 500 tons). From the tropical and sub-tropical Pacific it reaches, during the Summer months, the coasts of Valparaiso, where it is mostly consumed fresh.

38.—*Katsuwonus pelamys* (L.), (CACHURETA). It is found in the waters outside of the coastal current, from Huasco (28°27'S) northwards, and it is caught in comparatively small quantities.

39.—*Sarda chilensis* (Cuv. et Val., 1831), (BONITO; 4000 tons). It is found in great quantities along the coasts of Antofagasta and Tarapaca, and is the fish which constitutes the basis of the canning industry of northern Chile.

40.—*Pneumatophorus peruanus* (Jordan and Hubbs, 1925), (CABALLA). It is of small size and it is abundant in the coast of Tarapaca where it is caught in large quantities.

Family *Xiphiidae*

41.—*Xiphias gladius* (L.), (PEZ ESPADA; 1000 tons). This is a cosmopolitan species of warm seas which is abundant in northern Chilean waters. It is mostly exported frozen to the United States of America.

Sub-Order *STROMATEOIDEI*

Family *Stromateidae*

42.—*Stromateus maculatus* (Cuv. et Val., 1833), (PAMPANITO). From Tierra del Fuego to Coquimbo. Small; it is caught in limited quantities and is liked by the fishermen.

Family *Nomeidae*

43.—*Seriolella porosa* (Guich., 1848), (COJINOVA; 400 tons). From Magellan to Tarapaca; found gathered in small schools during the Summer pursuing the sardines.

Sub-Order *MUGILOIDEI*
Family *Mugilidae*

44.—*Mugil cephalus* (L.), (LISA; 100 tons). Lives in schools near the beaches, and enters the estuaries of the rivers of the central region, where it is sometimes found in extraordinary quantities.

Family *Atherinidae*

45.—*Austromenidia laticlavia* (Val., 1835).

46.—*A. regia* (Humboldt, 1833).

The numerous Chilean species of this family, known by the common name of PEJERREYES, constitute a systematic problem not yet solved. They are found all over the Chilean coast as well as in fresh water. They are very much appreciated and the annual catch is about 500 tons.

ORDER *GOBIESOCIFORMS*
Family *Gobiesocidae*

47.—*Syciases sanguineus* (Muller et Troschel, 1843).

48.—*S. chilensis* (Brisout de Barneville, 1846).

49.—*Sycyogaster marmoratus* (Jen., 1842).

These three species live attached to the rocks in the breakers area, from Chiloé as far as Perú. They are known by the common name of PEJE-SAPOS, and the fine flesh is very much appreciated.

ORDER *BATRACHOIDIFORMS*
Family *Batrachoididae*

50.—*Aphos porosus* (Cuv. et Val., 1837), (BAGRE DE MAR). Reaches the coast to spawn in the fissures of the rocks near the intertidal zone, around the middle of Spring, and leave the coast by the end of the Summer. During this period it is caught in large quantities in its lurking places to the end of poles. Its flesh is of excellent quality, but it is very little known in the market.

OCEANOGRAPHICAL AND FISHERIES RESEARCH IN INDIA

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Earlier Work

Although earlier investigations in Indian Seas were conducted by the British Naval Vessels from 1832 to 1862, serious attempts to study Indian waters were commenced only in 1872 with the inauguration of the Indian Marine Survey. The surgeon-naturalists attached to the survey ships were really the pioneers in marine studies of Indian waters. The Marine Survey was placed on a more permanent footing when the survey ship "INVESTIGATOR" was built during 1879 to 1880 and it is of interest to record that some of the apparatus used in this ship for work in Indian waters originally came from the gear used by H.M.S. "Challenger." The interest evinced in deep sea life by the Challenger Expedition was reflected in the special attention given to deep sea organisms of the Indian Ocean. Except for soundings and temperatures, the observations made were largely biological.

Sewell's Work on "Investigator"

In place of the "INVESTIGATOR I", a new ship of the same name was built and commissioned in 1908 commencing a new phase in oceanographic work in Indian waters with special reference to the temperature and salinity distributions up to a depth of 500 fathoms initiated by Sewell, who joined the ship in 1910. The work of Sewell on "INVESTIGATOR" continued till 1925 with the exception of a break of some years between 1914 and 1921 owing to World War I. Sewell's work brought out the general picture of hydrological features of the ocean. In a series of contributions published by the Asiatic Society of Bengal in 1925–35, the geography of the Andaman Basin, the nature of the sea bed and of the deep sea deposits of the Andaman Sea and the Bay of Bengal, the maritime meteorology of the Indian Seas, the temperature and salinity of the coastal and deeper waters of the Bay of Bengal and Andaman Sea, the topography of the Laccadive Sea and the coral formations in Indian waters were dealt with by Sewell. Additional oceanographic data were also obtained during this period from the results of the German Deep Sea Expedition "VALDIVIA" (1898–99) and

the Danish Dana Expeditions (1920–22) and the Dutch Snellius Expedition (1929), and to a smaller extent by traverses made by other survey ships.

John Murray Expedition

The third phase in the progress of Indian Oceanography relates to the period covered by the John Murray Expedition to the Indian Ocean on the research vessel "MABAHISS" led by Sewell. The region especially chosen was the Arabian Sea, to the west of Maldive and Laccadive Archipelago, in continuation of the "INVESTIGATOR" work. The expedition was able to confirm some of the findings of the Dana on the submarine contours and it brought evidence of the presence of submarine ridges running parallel to the Rift Valley system. The changes in the distribution of fauna in regions of the Arabian Sea were also clearly shown by the work of the John Murray Expedition, and a noteworthy discovery was made of the existence of large azoic areas off Arabia probably connected with petroleum formation. The results obtained by the John Murray Expedition have been dealt with in various volumes which have already come out, but the principal findings have been dealt with by Sewell in various papers.

Features of the Indian Ocean

Our present knowledge of the Indian Ocean has been summarized by Schott (1935), Sewell (1937), and Sverdrup *et al.* (1950). The fact that oceanographic information relating to the Indian Ocean is imperfect has been often stressed and with more intensive work it is possible that some of the concepts now current may require modification. This is especially so for that part of the Indian Ocean south of the Equator. The Northern part of the ocean is broadly divided into the Arabian Sea and the Bay of Bengal, each with further geographical sub-divisions. The topography of the Arabian Sea is characterized by the existence of a long series of submarine ranges, the Carlesberg Ridge beginning from the region of the island of Socotra and Gape Gardafui and extending to the southeast along the Chagos Archipelago and further south to the Island of Rodriguez. To the southwest of the Carlesberg Ridge and lying parallel to it lies the Mascarane Bank covering the Islands of Seychelles and Mauritius together with a series of reefs. To the north, the Carlesberg Ridge is continued by a different formation in the direction of Arabia and the Gulf of Oman; this ridge which is considered as the submarine continuation of the Kirthar Range of Sind is the Murray Ridge. The geology of these ridges and the sea floor require much further study before their origin could be established

with certainty. In the Bay of Bengal a north to south range, the Carpenter's Ridge, which probably is of volcanic origin, is situated to the west of the Andaman-Nicobar chain of islands. The mouths of the Indus in the Arabian Sea and the Ganga-Brahmaputra at the head of the Bay of Bengal have given rise to deep submarine gulleys (Indus Swatch and Swatch of no ground). The presence of the submarine ridges and gulleys substantially influences the circulation in the Northern Sector of the Indian Ocean. Further, there are widespread formations of coral reefs of the fringing and atoll types throughout the area except on the two sides of the Indian peninsula, although reefs are prominent around southernmost India and Ceylon, the Andaman-Nicobar group and the Laccadive-Maldive group. The reasons for their absence in most parts of the Indian Coast have not been satisfactorily explained, although it is usually attributed to estuarine influences and silting on the east coast of India and to the upwelling of colder waters on the west coast of India (Sewell, 1937).

Hydrologically the Bay of Bengal and the Arabian Sea present substantially different features and a careful study and interpretation of these differences might well explain the enormous disparity in fish production between the western and eastern coasts of India, the former contributing to more than two thirds of the total. The Bay of Bengal waters are generally less saline owing to the influence of the large rivers that empty into it. The eastern coast is also characterized by a well-developed estuarine fauna. On the other hand the salinity of the Arabian Sea waters is distinctly higher and the waters generally are of an oceanic character. Owing probably to the upwelling of deeper waters to the surface, the vertical mixing facilitated by the Carlesberg and Murray ridges and the turbulence resulting from strong S. W. Monsoon winds, the Arabian Sea waters appear to be richer in nutrients having extensive areas of high productivity. It is noteworthy that shoals of plankton feeding fishes like the oil sardine of Malabar (*Sardinella longiceps*) and the Indian mackerel (*Rastrelliger kanagurta*) largely contribute to the west coast fisheries of India.

Post War Interest in Fisheries and Oceanography

It may be said that the work carried out so far did not form part of any comprehensive programme for the investigation of Indian waters. Collection of further information has continued through the agency of survey ships and subsequent expeditions like that of the *Discovery II* and the *Galathea*. With the end of World War II, India, like many other nations of the world, was faced with problems of acute food shortage, and one of the subjects that received governmental attention was

the development of marine fisheries. It is natural that in connection with fisheries programmes a considerable amount of interest was also evinced in the further pursuit of oceanographical studies as an aid to the proper exploitation of marine fishery resources. A very small part of biological and chemical studies as a necessary ancillary to the development of fishery investigations was initiated in 1948 when arrangements for the systematic collection of hydrological data at selected fishery centres were made. These attempts to obtain hydrological data have been purely from the standpoint of fishery work and it cannot be said that they have been carried out in any systematic manner in the absence of a Fishery Research Vessel for regular cruising.

It is well-known that the arrival and departure of shoals of fish in any definite area are largely governed by their movements connected with their feeding and spawning habits, which are most intimately related to the physical and chemical properties of the sea water in which the shoals are located. In the sea there are periodical fluctuations in the physico-chemical conditions which may be annual, seasonal or even diurnal; these fluctuations are the combined results of the action of various meteorological and hydrodynamical factors. In addition to these more or less normal variations there may also be abnormal variations caused by geophysical disturbances or by factors unknown to us at the present time. A very systematic approach to these various problems is necessary to obtain a correct picture of sea fisheries of the Indian coast, which are largely seasonal and some of which, like sardines, show large variations from year to year.

Indian marine fisheries are largely seasonal in character and the causes governing the movements of shoaling fish and the reasons for the failure or shift of seasons of a given fishery are at present unknown. Similarly the fishing grounds have not been charted, though a beginning has been made in this direction for areas around Bombay. The area now exploited for sea fishing includes only the narrow coastal zone of five to six miles from the shore. Power vessels to exploit the off-shore fisheries have begun operations on a pilot scale in Bombay under the aegis of the Government of India and in Calcutta by the Government of West Bengal. In the not too distant future, it is expected that more vessels will be put into operation from different centres like Cochin, Madras and Visakhapatnam. The work of exploration of off-shore fishery resources and the charting of fishing grounds is one which calls for help from oceanographical studies as data on movements and composition of the water masses would be extremely useful.

Central Board of Geophysics

The Government of India constituted the Central Board of Geophysics in 1949 and an Oceanographical Committee of the Central Board of Geophysics reviews the problems of oceanographical studies in India from time to time with the ultimate object of setting up an Institute of Oceanography. This probably marks the first attempt in the country to think in terms of oceanography as an independent science which needs pursuit for its own sake without being subservient to the applied aspects of Fisheries, Harbour development, Coastal erosion, Tide Prediction, Survey and Navigation. It may be recalled that the Survey of India has for a long time been carrying out prediction of tides for thirty-nine ports from Aden to Singapore and it is also responsible for the mean sea level determinations. Expansion of tidal work is also contemplated by the Survey of India by placing tide gauges at most of the important ports and carrying out corresponding meteorological surveys with the help of the India Meteorological Department.

Extent of Available Data

The information on oceanographical topics available in India would therefore comprise (1) Salinity and temperature distributions as recorded by previous expeditions and part of which work is being continued with reference to Fisheries by the Central Marine Fisheries Research Station at Mandapam with the help of Fishery Naval and Merchant Vessels operating in Indian waters; (2) Data relating to tides, mean sea level and other physical aspects available with the Survey of India; and (3) Data on maritime meteorology available with the India Meteorological Department.

An extremely useful compilation of sea temperature, currents and meteorological data has been published by the Netherlands Meteorological Institute in the form of an Atlas in 1952.

Beginnings of Fisheries Research

Early attempts relating to research on marine fisheries of India were directed to experimental trawling operations by ships belonging to the Madras, Bengal and Bombay Governments and the scientific work relating to the biology of the Oil Sardine of the Malabar Coast. The trawling operations were commercially unsuccessful and fishery work in most provinces suffered neglect during the periods of economic depression that followed the first World War. The interest in the Sardine fishery of the west coast of India continued because of the disasters which this fishery suffered following the many successful years

for Sardines which led to the production of sardine oil becoming an important industry. Owing to the inadequacy of staff, lack of sufficient funds to carry out investigations with thoroughness, and the position of Fisheries as a Provincial Subject creating administrative problems when a fishery extends to two or more states, these efforts often lacked continuity. The first decision to tackle the marine fisheries investigation on an All-India basis was taken by the Government of India with the starting of the Central Marine Fisheries Research Station in 1947.

Central Marine Fisheries Station

This Central Institute was started in February 1947 for handling marine fisheries research on an All-India basis with temporary headquarters in the Biological Laboratories of Madras University until the permanent headquarters at Mandapam were ready for occupation. Buildings originally put up as a Naval Hospital by the Defense Department during World War II were converted into laboratories and temporary residential accommodation for the staff. Subsequently an aquarium was built with facilities for keeping organisms alive in circulating sea water and fittings to the laboratories were carried out. In addition to the headquarters station, there is a subsidiary research station at Kozhikode to deal with the special fisheries problems of the West Coast of India, and research units at Karwar in the Bombay State to deal with the mackerel fishery, at Narakkal in Travancore-Cochin to deal with the prawn fisheries and prawn farming operations, at Madras for handling studies on edible Mollusca and at Bombay for carrying out investigations on off-shore fisheries. In order to collect fishery data from the long coast-line of India, fishery survey assistants have been posted at twelve centres representative of the various divisions of the Indian coast-line extending from Kathiawar to West Bengal. The data gathered are analysed and computed at Headquarters, setting up for the first time a machinery for the collection of All-India marine fishery statistics.

Programmes of Marine Fisheries Research

The work of the institution is broadly divided into four categories, Fishery Survey, Fishery Biology, Marine Biology and General Physiology. Fishery Survey aims at assessing the marine fishery resources by computing fish landings and biological composition of catches to see if the marine fisheries in general are under- or over-utilized. Scientific study of exploratory work of the deep sea fishing vessels forms an essential part of the survey programme. The studies relating to Fishery Biology deal with the fish stocks, special habits, distribution, life-histories and such aspects of fish life as have intimate bearing on fisheries

problems. The major fisheries of India like the Sardines, the Mackerel, the Sharks and other less known categories of fishes are all investigated in detail in an attempt to understand the causes governing their abundance, and the efficiency with which the fish are caught and utilized. Subsidiary fishery resources like the prawns, the oysters, clams, etc. are also receiving close attention. Sea weeds which occur in considerable abundance in the sea and form a valuable raw material for the production of agar and other industrial products, are being investigated in detail to determine the extent of the resources. The third important category of investigations come within the field of Marine Biology dealing with the factors connected with the abundance of smaller forms of plant and animal life which ultimately form the food of fish. This is also correlated with studies on the chemistry of sea-water with a view to understanding seasonal changes in the occurrence of nutrient salts. Bacteriology of sea-water and fish products is also investigated with a view to arriving at enforceable standards in the handling of fish products. The physiology of fish and other commercially important forms of marine life are studied with a view to selecting suitable types that would be ideal for large-scale culture in coastal areas which could be developed into marine fish farms. The institution maintains a good library and a reference collection.

Correlation of Oceanography and Fisheries

In the above paragraphs some idea has been given of the approach to oceanographical and marine fisheries studies in India. There is need for a standing machinery to collect and integrate synoptic data on the hydrology and maritime meteorology of the waters that surround India. The emphasis so far received has been biological and although marine biological investigations on a considerable scale have been carried out at Visakhapatnam, Madras, Mandapam, Trivandrum, Calicut and Bombay, the full interpretation of these results has to await more intensive physical-chemical work. Preliminary chemical data on phosphates, nitrates, nitrites and silicates are already available for Madras, Mandapam and Calicut and it is hoped to extend these further in the near future. The greatest drawback, however, lies in the fact that studies have principally been carried out in inshore or neritic waters with few observations in the open sea. An attempt to obtain a clear picture of oceanographic conditions in relation to Fisheries has now been initiated by the Central Marine Fisheries Research Station from Bombay utilizing the facilities of deep sea fishing vessels operating from that port and especially in view of the excellent results in trawling operations to the west of Kathiawar, which has now been found to be

one of the richest fishing grounds in India. A new line of work to correlate fishery conditions with oceanography has been developed in the study of mud banks of the Malabar Coast where it has been established that the fine silt which settles soon after the southwest monsoon in the form of a submerged bank acts as a reservoir of nutrient salts, probably influencing the fisheries of that area. On the physical side, work has been started by the Indian Navy in the Port of Cochin. There is need for more detailed coastal surveys and accurate charts and maps for the entire Indian coast, and for this purpose the surveys which are being repeatedly carried out by the survey ships will, it is hoped, contribute a large amount of data.

Future Prospects

Oceanography is an infant science in India as compared with the status of the subject in the more advanced countries where work has been in progress for some years. Absence of adequate training facilities for physical oceanography at Universities and non-availability of suitable research vessels for oceanic work constitute the major obstacles to progress, but there is every reason to think that these will be overcome. The Andhra University on the East Coast of India has already formed a Department of Geophysics, and has initiated some work on physical and biological oceanography at Visakhapatnam. A few Indian Research Scholars are being trained abroad on the subject. Research Vessels for oceanographic and fisheries work are likely to become available under the Five-Year National Plan of the Government of India and substantial additions to equipment available for marine work are now being made at several centres of Research. These developments in a country situated in one of the least explored of oceans will be watched with interest by all students of Marine Science.

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OCEANOGRAPHY AND FISHERIES

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The contribution of oceanography to fisheries research (which means research in economic and technical fields as well as in biological fields) is to be understood only in terms of the applied character of fisheries science: an effort is made in the following paragraphs to expound the implications of this statement. However, it is desired here to stress a principal consequence of this position, namely that it brings upon the fishery scientist an obligation to exercise a keen discrimination, and to undertake a frequent scrutiny of his activities, to determine whether they will stand a test of their applicability to real fishery problems.

1. Some Definitions

The term Indo-Pacific is used in the sense in which it is employed by the Indo-Pacific Fisheries Council, namely, to signify the zoogeographic area occupied by the warm-water marine fauna which is variously described as Indo-Pacific, Indo-West-Pacific (Ekman), and Indo-Australian (Weber and de Beaufort), the core of which is constituted by the Indonesian Archipelago. The term oceanography is taken to be the correlative of limnology and thus with that term to comprehend the whole of the scientific work bearing upon the hydrosphere with biological objective, or of biological use. This definition derives authority from many works from among which perhaps that monumental, and already classical work "The Oceans", by Sverdrup, Johnson and Fleming, may be chosen for citation. The validity of regarding oceanography as correlative of limnology may be found in the comprehensiveness of the latter, as set out in such standard periodicals as the Revue der Internationale Gesammte Hydrobiologie and also in the standard text by Welch, which uses that term as title.

It is to be stipulated that we reject the restriction imposed upon the term by some workers who regard it as concerned only with physical and chemical features of the oceans, and even as especially the preoccupation of naval research establishments. Whilst, of course, there can be no challenge of their right to choose this usage, their attention may

well be drawn to the confusion which they create, especially since they do not offer us any alternative correlative of limnology.

Oceanography is used by us to signify the study of the oceans in respect of themselves as water masses and of the biota which inhabit them; if not qualified, as it is in expressions such as 'fisheries biology', it is a pure science with no limitations upon the range or detail of the subject matter of its enquiry. A qualifying term, such as "fishery", signifies an orientation of the enquiries and a limitation of the field, and not a specialized extension; thus, fisheries oceanography is that investigation of the physico-chemical and biotic properties of the oceans required by fishery science—it does not mean oceanography which has swallowed fisheries research!

2. General Consideration

In a general way we may say that oceanography holds a relationship to fisheries corresponding to that which meteorology holds to agriculture. But we must go further and describe it also as the 'soil-science' of fisheries. These two aspects were discussed by Tait, in his Auckland lectures, from the points of view of physical and chemical properties of the sea, respectively, in relation of fishes. The more general, as well as more particular aspects of relations of aquatic organisms to the physical and chemical factors of their environment, have been described in the new voluminous literature of ecology. In this paper I wish to make a plea, both for a special fisheries view of these relations and, at the same time, for further and more detailed investigations along what might be described as the classical approach to animal physiology and ecology.

The programme of fishery biology traverses, in a general sense, six principal phases, a brief description of which I quote from a recent paper I presented to the General Fishery Council for the Mediterranean.

"Firstly, if the area in which the biologist is working is virgin a survey must be made to determine the general characteristics of the area and of its fish stocks; the principal compositional features of the stocks must be described. For most of the present fishable areas information such as this has been accumulated in the course of fishing operations and from work in marine biology; in such cases, a late starting programme in fishery biology must first collate all such information.

"Secondly, the general features of the stocks of the species to be investigated must be determined. The species must be correctly identified, and the continuity and taxonomic homogeneity of these stocks must be examined. This work may or may not require the refined

taxonomic study known as racial investigations, but it is in any case a distribution study which must take reference to details in the bionomics of the species.

"Thirdly, the bionomics of the species must be discovered, that is the general-life-history, ontogenology (embryology, growth, and gerontology), including feeding habits, reproduction and migratory habits.

"Fourthly, the composition of the stocks is to be determined and, if the stocks exist in separate units, this determination must be made for each separately. This compositional study concerns the age, sex, size, and maturity and other groups of the population.

"This analysis generally reveals a fluctuation from year to year in composition of the stocks. Frequently there is also considerable variation from area to area and between distinct segments of the stock. This study should see, not only to describe the composition and its fluctuation, but also to discover the causes of these fluctuations and, if possible, to evolve a system of prediction of the appearance of the fluctuations.

"Fifthly, following directly out of the fourth stage, there is to be a measurement of the properties of the population. These properties are potentials for growth and reproductions, and viability as a complement to the mortality which the stock sustains. In this stage there is affected a considerable concentration of information since not only are data on the bionomics and composition of the stocks to be reduced into expressions summarizing the consequence of these structural features, but there must also be a reference to physiological, physical and other data concerning the factors which determine the properties of the population as a whole. This work should also aim at a prediction system.

"Sixthly, the fishery biologist must then collaborate with the fishery economist and fishery technologist in applying the general theory of fishing to give mathematical expression to the relations between the properties of the population and the effect of fishing operations."

The essential feature of this programme is that it is concerned with populations: its purpose is to develop a detailed description of the population as a whole and of the response of the properties of the population to changes in its environment, including among such changes, of course, those in fishing intensity.

The biologists' responsibility in respect of these populations is one or the other of two kinds, which may be summed up in two questions: Firstly, what type of population and where? Secondly, of what abundance? The first question belongs in the main to the exploratory stage, the second to the management stage. In a way, also, these questions correspond to the different enquiries concerning abundance; those which relate to the availability of the fish to fishing operations, and

those which relate to the real abundance of the stock; and these in turn are covered respectively by the first three and the last three of the stages listed above.

3. Oceanography and the Distribution of Fish

In its broadest sense this is a question primarily of marine zoogeography, but for the fishery biologist the enquiry must press far deeper, since, in point of fact, for each species of commercial importance he seeks to establish the ontogenetic distribution patterns and, moreover, the seasonal, annual, and even secular modulations of these. The great oceanographic cruises, of the Challenger and of others, have since established the major features of our picture of marine zoogeography and yet withal there remains much to be done to enable us to evaluate unexploited areas and to be able to give fishermen the information on which they might plan the development of fishing operations.

The zoogeographic account of the distribution of marine faunas is in effect a generalized one referring to groups of species and to individual species which characterise the fauna and serve as indicators of identified conditions. The distribution patterns referred to in the zoogeographic account indicate the broadest limits within which the faunas are observed to occur.

The more restricted limits within which the various ontogenetic stages move are not of as great importance to zoogeography as they said their seasonal and other modulations are to fisheries. But the greater pattern and its component parts are both the grosser manifestation of the reaction of the individual organisms to the various elements of its environment at the behest of its own physiology. The general adjustment of the organism to its medium in respect of its respiratory and osmo-regulatory requirements set the general limits within which it can move differences, in these requirements, between ontogenetic stages may, theoretically, give separate distributions to these stages. The nutritional requirements and peculiar needs in respect of reproductive habits, further complicate the picture as the organisms undertake feeding and reproduction migrations in search of the situations where the necessary conditions are satisfied. It is perhaps no misrepresentation to say that in the first part of this enquiry, the task is to describe the distribution of the first and the conditions under which they are found, whilst, in the second part, the task is to find means of predicting where these conditions will be found—as a means to predicting where the fish will be. It must be stressed, however, that the accurate account of distribution requires elucidation of the keenomics of the species.

At this point we are concerned only with the types of fauna found in various situations, with the task of characterizing an area in respect of the composition of its fauna and, for situations whose fauna is known, with evolving means of predicting variations in the distribution of elements of that fauna and of ontogenetic stages of those elements.

The role of oceanography in this phase of the programme emerges very clearly; it must first furnish the description of the physical, chemical and biotic properties of the water masses and in this way it corresponds to soil science coupled with climatology. Then, when the distribution patterns are revealed, the role of oceanography corresponds to that of meteorology in furnishing predictions as to the conditions which are likely to be found, and the task of the fishery biologist then is to predict the behavioral response of the fish stocks to such conditions.

4. Oceanography and the Abundance of Fish

In this part of the programme we may consider three types of problems having common basis. We are concerned with the natural abundance of fish in an area, a problem which has practical meaning only for unexploited areas, although a method of estimating potential natural abundance of an exploited stock might solve many of the problems concerning abundance under conditions of exploitation. Next we are concerned with the fluctuations in abundance which have manifested themselves in all exploited stocks, whatever the degree of exploitation. Finally, we are concerned with the special problem of the effect of fishing operations on the abundance of the stock.

The measurements of natural abundance of stocks in virgin areas is a task of peculiar difficulty which demonstrates, perhaps more than anything else, the special character of the work of fisheries science and the abstruseness of its problems. A simple example will serve to indicate the nature of the problem and the difficulties. Somali fishermen have for many years been catching tunas off the Somali coast, and for some years a few small canneries have been processing this catch for export market. The canneries would like to expand their operations and therefore require to increase their catch of tuna; the question is: do substantial stocks of tuna, accessible to fishing craft operating from Somalia, inhabit the waters on the Arabian Sea east of Somalia, or, are the occurrences from which the fishermen have made their catch merely sporadic invasions from a principal area lying somewhat remotely from Somalia? This, it will be noted, is not a simple distribution question, for the tuna are well known to appear in these waters. It might be a question of ontogenetic distribution pattern and the determination of this possibility could lead to development of a system of prediction of

the times and conditions under which these occurrences take place, and even of the fluctuations in relative numbers of fish appearing from time to time. But this would still be insufficient: the cannery operators need to have some indication of the level of abundance in order to be able to decide the amount of fishing equipment (craft and gear) which could be brought to bear on the stocks, and thence the amount of processing equipment which would be required to handle the catch.

There are probably two broad avenues of approach to this problem. One is by way of evaluation of the area in terms of basic productivity and measurement of food chains. This would be possible only for stocks endemic to the area and not to transients. The other approach is by way of special sampling which, in the case of pelagic stocks, may include aerial observation. It may be noted that in this field of work there is urgent need to elaborate and improve the methodology of searching and sampling, and that in such improved methods, even greater use must be made of reference to oceanographic factors as determinants of the behaviour of the fish.

In the more general sense of the productivity of an area, the oceanographer must take a leading role, and the task of the fishery biologist is to develop the understanding of the nutrition of the economic species in order to be able to use the data on food availability.

We now turn to the other two problems concerning abundance. The structure of the problem was symbolized by Russel, in his well-known equation, which says that the difference in a stock of fish, between one season and another, can be represented by the balance between.

Growth + Reproduction and Natural Mortality + Fishing Mortality. We may take these four elements as the plan for our enquiry.

Growth:—The growth of any individual may be taken to be the result of the operation of factors which may be considered in three groups—genetic, food supply, and the environmental factors affecting food procurement and the subsequent metabolism; between these arise interactions. In the past fishery biology has concerned itself chiefly with measuring and describing the ontogenetic manifestations of growth: it has made little analysis of growth itself as physiological process. The initial approach made by fishery biology to growth has furnished a useful description of growth phenomena at what might be called their grosser level, and some attempt has been made to measure the relations between these phenomena on the one hand, and food availability and environmental conditions on the other. Whether much further progress can be made along this line before more detailed enquiry is made into the physiology of growth might be questioned, but both types of enquiry

require much information from oceanography on the environment of the fish. The first information is that concerning food availability; the second is that concerning temperature, salinity, trace elements and biotic factors which influence the procurement of food it ingests. But the work of fishery biology has been concerned generally with estimates of average growth in populations, and with this as a means of characterizing year-classes and the conditions prevailing from year to year. Recent work has carried the theory further to attempt to use those data on growth as a means of estimating the biomass production of the population as a whole. Such work will accomplish a practical effectiveness, however, only after the underlying physiology of nutrition and growth have been studied further, and this will mean, as in the study of nutrition and growth of domestic animals, that there must be controlled experiments in which both food supply and environmental factors are at least precisely measured if not actually controlled.

In this field of enquiry, taking it to be the responsibility of fishery biology to measure the growth of the population, the contribution of oceanography is two fold: initially, in aiding the description and analysis of these systems; subsequently, in providing data for a prediction system. In the initial phase the contribution is of data on all factors which might directly or indirectly affect the nutrition and growth of the fish. In the prediction phase, the data would concern certain critical factors.

Reproduction:—Although in the fishing theory equation this term refers essentially to recruitment into fishable stocks, the fishery biologist has some concern with the whole range of phenomena which lead to the reproductive act and those which lead from that act to recruitment. That is to say, there is a concern with sex ratios and fecundity, with length and age at first maturity, and (within each season) of the maturation of the gonads, with the spawning act itself (including fertilization), with embryonic development and hatching, with larval and post-larval development, and with growth and survival through these and the young-fish stages. Some workers consider that the only practicable approach to the problem of replenishment of the stock is by way of measurement of recruitment as it is taking place, or of the potential recruits shortly before they enter the fishery. Other workers contend that it is possible to enter more deeply into the system and to attempt some measurement of the series which connects spawners with recruits. Among these latter there are some who believe that, although in general the number of eggs produced at each spawning is always far in excess, in numbers, of the number of individuals which survive to be recruits to the fishery, so that little connection can be found between the number of eggs spawned and the subsequent recruitment, the brood

strength is, in the main, determined by one or more critical factors at certain critical points in the life of the brood. Efforts at demonstrating this hypothesis have aroused some controversy. However, it is unquestionable that the sequence described above is closely dependent upon environmental conditions and that any understanding of it, let alone any measurement of it or formulation of a prediction system, must make demands upon oceanography.

Natural Mortality:—This term is perhaps even more recalcitrant than the other two. We may argue, a priori, that mortality may be caused by predatism, parasitism, disease, lethal genetic characters, malnutrition, and physical factors such as temperature and salinity extremes, but there seems to be little prospect yet of measuring the result of operation of each of these factors separately, or, as an antecedent to that result, the intensity of each factor. Nevertheless, again we must look to oceanography to furnish the fishery biologist with some of the information which he will require in this field. At the present stage natural mortality must be accepted as a sum arrived at after deducting measured fishing mortality from estimated total mortality. It might be possible to correlate variations in natural mortality with variations in environmental factors and thus to approach both analysis of the causes and prediction of intensity.

Fishing Mortality:—In this field, oceanography has a small contribution to make in respect of the influence of weather and sea conditions on the intensity of fishing operations and their efficiency, but we defer further consideration of this to Section 5 of this paper.

Fluctuations in Abundance:—A great deal of work has been done in describing the fluctuations in abundance of exploited stocks and analysing these fluctuations in terms, chiefly, if variations in strength of brood-classes and in recruitment into fishable stocks. This work can proceed at one or other of various levels: either with simple description of the fluctuations and elementary correlation with various environmental factors—a course which does not promise much reliability in its results; or with varying degrees of penetration of the analysis into the systems, with the conviction that if relationships are truly identified, and relations usefully measured, prediction systems may be evolved with practical and reliable value.

Fishing Theory:—Perhaps the ultimate objective of fishery science in respect of fishing operations is to prepare, for each unit fishery, a description of the fish stocks and of the effect on them of the fishing operations in order to permit the design of a plan of management of the fishing operations which will ensure the best exploitation of the stocks. The description of each unit fishery will be along the lines of

the Russel equation as discussed above, and the dependence of this work upon oceanographic inquiry is clear.

Best exploitation clearly means that which will give the best and most sustained yields, but in another way it may be signified by the term "fish husbandry"—a concept which has recently emerged in respect of marine stocks and which, at least, holds out a goal, even if we should be ready to find that the end-result might not be as precisely analogous to animal husbandry as our present speculative thinking imagines it. This touches upon the possibility that there might be other direct intervention in the stocks besides the fishing operations. Some speculative thinking has turned to the possibility of intervening in some of the basic phenomena of the sea, and there has been experimentation in fertilization. The realization of artificial upwellings, or of control of the movements of marine stocks, will depend very largely on the work of the oceanographers.

5. Oceanography and Fishing Operations

The dependence of fishing operations on weather and sea conditions needs no discussion, either in respect of the effect of environmental factors on the behaviour of the fish (which determines gear and method) or of the effect of weather and sea surface conditions on the craft. The point to make here is that fishermen need more aid from the oceanographers by way of predictions of these conditions.

6. Discussion of the Relations between Oceanography and Fisheries

There is really no need to make a case for recognition of the importance to a knowledge of any organism (or population of organisms) of data concerning its environment, and as oceanography is defined here, it is the science which will furnish the environmental data required by the fishery biologist. I do not believe that it can be denied that in fact fishery science can no more do without oceanography than agricultural science can do without meteorology. But, whereas oceanography *per se* has the entire marine hydrosphere as its field of enquiry, and the limits are set only by the interest of the worker and the funds, equipment and help available to him, fisheries oceanography is to be defined strictly according to the area of interest and the kind of problem presented by the fishery biologist.

It will be clearly seen from the preceding discussion that different types of oceanographic information are required in the different situations found in fisheries. Different sets of elements are to be observed, with different patterns of observation station, and different intensities of observation at each station according to the nature of the fishery problems. In the determination of general limits of distribution of a

fauna, or a species, broad isotherms, isohalines and so forth are sufficient, but for more detailed description of distribution, a more precise measurement, with much narrower intervals between the iso-lines, is required. The point which must be made is that the oceanographic programme for fisheries should be carefully planned with a clear view of what is required by the biologist's problem and of the use which he can make of the material and data which are collected. And perhaps it would not be dogmatic to say that where resources for oceanographic research are limited, these should be employed in those situations in which the need for oceanographic data can at once be formulated, rather than in broader fields from which the data may be expected to be of use at some unspecified time in the future.

7. Oceanographic Requirements in the Indo-Pacific

On the basis of the foregoing review, and making use of some of the criteria proposed for setting limits upon the oceanographic programme for fisheries, we may make a brief review of some of the urgent problems for oceanography in this region.

In the first place it is as well to refer to the important problem of the basic productivity of tropical waters. This has now become a critical question, the solution of which would have considerable bearing on the planning of future development of fisheries. However, it is a long range problem which, at this stage, stands within the province of the oceanographer with his more general interest. Moreover, it is probable that further advances need to be made in perfecting the techniques for measurement of productivity and in marine biological research on food chains and the nutrition of marine organisms.

Turning to immediate fishery problems, mention may first be made of the 'major' fisheries of the region, such as for the *Rastrelliger* spp. of the Indian and Malayan west coasts, of the Gulf of Siam and of Indonesia, the *Sardinella longiceps* in much the same areas, *Stolephorus* spp. also in similar areas, *Sardinia* sp. in Japanese waters, the reef stocks predominantly of Percomorph species, the *Pseudosciaena* spp. of the China Sea, the Flying fishes (Exocoetidia) of the Celebes and those for the Carangids and Scombroids, more especially within the various island groups. In respect of each of these fisheries the requirement is for oceanographic information bearing upon the distribution of the fish, and the related work concerning the bionomics of each species. In some cases the broad distribution limits are known and the present problem is to determine the distribution of ontogenetic stages and to develop prediction systems; Rastrelliger in the Gulf of Siam, Sardinia in Japanese waters, and Pseudosciaena in the China Sea are in this situation.

In other cases the situation calls for a more general exploration of distribution and analysis of compositions; this is especially true of the reef stocks. In all of these cases there is need of estimates of level of abundance, in none of them, except perhaps the Japanese sardine, does the present knowledge of the stocks warrant the mounting of oceanographic programmes appropriate to a true population analysis as described above.

The foregoing instances are all of well established fisheries which stand in need of improvement in the knowledge of the biology of the resources. Of different status are two other broad classes of resources: the pelagic stocks of the high seas, and the demersal stocks of certain continental shelf areas. The latter include the continental shelf of the Indo-Pakistan west coast, of the Bay of Bengal, or the deeper waters of the Gulfs of Siam and Tonkin, of the South China Sea, and of the Java and Arufura seas. Although there has been some exploration of these areas, and in some cases (e.g. off the Saurasthra coast) some systematic fishing, the knowledge of the areas is generally patchy and incomplete; as soon as the development plans of the fishery industries of the adjacent countries warrant, there should be systematic exploration and survey of these areas, and this work should include the taking of appropriate oceanographic observations. Similarly, in the case of the pelagic stocks, survey work must be undertaken at some time and must include oceanographic observations.

As a final note, I may say that, whatever my remarks above, I do not underestimate the difficulty which confronts a worker, or a director of a programme, in determining the limits of the work and the relevance of different avenues of enquiry which open up as an enquiry develops. One can only say that this must be left to the perspicacity and honesty of the worker. One cannot deny the desirability of general oceanographic enquiry, any more than the urgency of particular enquiries, demanded by economic necessity, can be ignored.

FACTORS IN THE UTILIZATION OF CANADA'S PACIFIC MARINE RESOURCES

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In a simple society men use their hands or simple tools to take fish for their own immediate food needs. In an industrialized society complicated machines are used to catch and prepare fish for shipment and exchange for other commodities. In any region the extent and character of the departure from the simple situation depend upon (1) the qualities and habits of the fish species available, (2) the geography and meteorology of the region, (3) the technological aptitude of the fishermen, and (4) the economic condition of the inhabitants. These factors are also an influence in the attitude of peoples toward resource utilization. Their application to the fishing industry of the Pacific coast of Canada is discussed in this account.

Fish Used

Five species of salmon of the genus *Oncorhynchus* provide more than half the total value of the Pacific fishery in Canada. The fish are fat, preserved well by canning, freezing or salting, and are in general high demand. They differ substantially in life history but all are anadromous, and all attain most of their growth in salt water. On their spawning migration in summer and autumn all pass through the inlets and channels of the coast in large and readily captured schools. Thus, on its spawning migration each species is susceptible to easy depletion or even extermination by fishing. Human activities add to the natural hazards of the freshwater life of these fish: dams obstruct rivers; irrigation requirements divert water; impoundments "drown" spawning grounds; communities and industries pollute streams; logging and agriculture result in silted spawning grounds or changes in stream flow.

The second ranking fishery on the Canadian Pacific Coast is for herring (*Clupea pallasi*). Most of the catch is reduced and shipped to the markets of the world as oil and meal. Adult and adolescent herring for the most part spend their summers feeding offshore on the continental shelf. In autumn and winter they form dense schools and approach the coast as a preliminary to spawning in shallow water and on the beaches in March. The migrating aggregations are very vulnerable

to large scale capture. This suggests that intensive fishing operations could cause depletion. As it is beyond reasonable dispute that salmon can be depleted by unrestricted exploitation, it is assumed that herring can also be depleted by unrestricted fishing on pre-spawning populations. This assumption is the subject of critical scientific examination.

Of a dozen or so commercial species of groundfish the halibut is the most important. It freezes well and is shipped frozen to the markets of the continent. The fishery is principally by long-line in Hecate Strait (between the Queen Charlotte Islands and the islands along the mainland coast) and on the offshore banks of the continental shelf. It is administered by an International Commisssion (Canada and the United States) on the premise that at low or moderate levels of abundance, increased fishing effort produces less fish. The sable fish or black-cod (*Anoplopoma*), so highly prized for smoking, is taken on the same gear in deep water. The remaining groundfishes—flatfishes (*Pleuronectidae*), gray cod (*Gadus macrocephalus*), rock fishes (*Sebastodes*), lingcod (*Ophiodon elongatus*)—yield excellent fillets for the fresh or frozen trade on local or distant markets. They are taken principally by trawls on banks of intermediate depth (15–100 fathoms) at times when concentrations make for fast and hence profitable fishing.

The only truly oceanic fishery to attract Canadian fishermen is the troll fishery for albacore. The fish is canned as premium tuna for Canadian consumption or exported frozen. Fishing may be as close as six miles from shore but typically is offshore by 40 miles or considerably more. The fishery is very erratic in occurrence and yield. There is in it an element of sport which appeals to many fishermen.

A small but effective shore-based whaling operation uses half a dozen or more species of whales. The products (meal, solubles, oil, and meat for fur farms) are sold on the world's market. The promised rewards of the whaling industry are the only ones which have yet seemed sufficient to justify deploying valuable capital equipment in organized offshore projects. Canadian whalers work up to 150 miles off shore—much farther than other company-operated vessels.

Geography and Meteorology of the Area

The coast of British Columbia has many islands and inlets. Race Rocks at the south end of Vancouver Island and Stewart at the north end of the Portland Canal are less than 600 miles apart in a straight line, but 16,900 miles of coast line intervene. The irregularities in the shore line provide numerous good harbours where small craft can wait out perilous weather or conditions which make fishing impossible. Although there are many good harbours there are few or no permanent

residents on them. The shore in many places is rough and inhospitable and the surrounding terrain is so rugged as to make access by land difficult or non-existent. In consequence fishing communities are few and widely separated and those with rail or road connections are even fewer.

Tidal change is moderate (12 to 26 feet maximum change at various places). Tidal currents in the passages and inlets are, however, strong. In a few places they make navigation hazardous and in others they are too swift to be stemmed by small craft. They must be given thorough consideration for efficient navigation on the coasts.

The prevailing winds are moderate to strong with occasional calms and gales. Sudden high winds are not common. In deep water, seas are seldom dangerous to properly loaded seaworthy vessels. However, in the shallow waters of Hecate Strait or in situations where the wind opposes strong tidal currents, steep waves develop which can be dangerous to small craft.

Technological Position

The fishing industry of Western Canada has made use of the technological knowledge of the Western Hemisphere. It has been applied both to processing and to capture. The principal method of processing is canning. To it are applied the special techniques of machine cleaning of fish; and of filling, capping, exhausting, sealing, and retorting of cans.

The fish reduction industry uses presses and centrifuges especially adapted to its purposes and special evaporators for concentrating solubles in the press liquor. General plant construction and arrangement take advantage of new power sources and engineering methods.

The installations for the frozen fish trade apply principles of refrigeration engineering as developed by scientists of the Fisheries Research Board. Similarly, the application of newly developed principles to smoke house construction has improved control of the process to the point where the operation is largely freed of dependence on uncontrolled conditions.

The greatest single contribution of technology to catching is the development of compact, dependable, and economical power units to propel vessels and to operate deck equipment. More recent developments of great general usefulness are the radio telephone which facilitates concentration of the fleet on large bodies of fish and with shore headquarters or processing plants; and the echo sounder, which makes navigation more certain, allows troll and trawl fishermen to follow the contours of the bottom, and reveals the presence of deep schools of fish. General developments of more recent application are radar, which

facilitates prompt return to harbours in fog or dark, and the range finder and Loran for general assistance in offshore navigation.

The machines mentioned above were developed for other purposes and later adapted to fishing vessels. There are special developments, too. Prominent are power driven drums on the sterns of small boats for easily setting out and picking up gill nets (or handling long lines), larger drums for handling salmon purse seines, power driven gurdies for handling trolling lines, the older long line gurdies of the halibut boats, and stabilizers for trollers and other smaller craft. These are the products of the ingenuity and enterprise of fishermen. Other ideas are constantly being tested and rejected or modified. All increase the efficiency of fishing or reduce the physical labour of fishing and, in so doing, shift the emphasis for success in fishing from physical strength and hardihood to ingenuity and technical skill.

A variety of factors contributes to the rapid development of efficient fishing methods. The army of fishermen is not a stable one: it is always receiving recruits from (and losing deserters to) other industries—logging, farming, construction—so that new ideas, some practical, some naive, are continually being tried, with the good ones being adapted and applied to local conditions. Furthermore, Western Canadian fishermen are recruited from a variety of the great fishing centres of the world so that methods successful in other places are available for trial under local conditions. In general, there is ample opportunity to try and apply new fishing methods within existing regulations. When successful ones are developed, the educational standard is high enough to facilitate the ready dissemination of information through trade and technical journals. The organization of the industry is at once strong enough and adaptable enough to bring promptly into general use all really useful developments.

Economic Position

The fishing industry of Western Canada is centred on a favoured section of a favoured continent. The inhabitants of British Columbia have no urgent need of fish as a protein food. Rather, they use the choicer varieties occasionally as a change from meat. In general the processed products of the fishing fleets are shipped to the markets of the continent and the world to provide exchange for the foods and manufactured goods which go toward maintaining a high standard of material welfare.

Application

The low local demand for untreated fish and the wages for labour expected by fishermen require that most of the fish be processed in one

way or another. In general this can be done most cheaply in the few large centres of population having good transportation facilities. A few specialized communities relying entirely on fishing products have been located at places convenient to the fishing grounds. Technological advances are improving established processing methods and developing new ones.

The Canadian fishing industry depends upon exports, and in consequence is in an assured competitive position only in cases where there are advantages in fish availability or in some other way. There is little incentive to organize costly offshore operations (such as for tuna) in competition with exploiters from other nations.

The vessels used must be large enough to deliver paying fares to fishing ports or buying stations which are rarely as much as a day's run from the fishing grounds. They must be large enough to continue fishing in moderate weather in order to complete paying loads, but they need not ride out severe gales as safe harbours are always within reach of the fishing grounds. The boats must, of course, be large enough to handle effectively the gear in use and to accommodate the necessary fishing aids. The tendency is accordingly toward the use of craft of medium size. Boats used in the marine fisheries are customarily 35 to 85 feet long depending on the gear used and the places and seasons of operation. Salmon gill net boats used in the inlets and river estuaries are smaller and lighter in construction.

Because the economic situation puts the emphasis on financial return rather than on efficient use of the whole resource, the fish utilized are those commanding the highest prices or those whose habits make it convenient to capture them in very large numbers. Only such species can produce sufficient return to allow the fishing profession to compete successfully for the time of potential fishermen. However, for these species more fishermen are attracted to the fishery than are necessary to take all the fish which can safely be removed from the reproducing stock.

As the most important fisheries in Western Canada are for anadromous fishes which are liable to depletion by over-fishing, regulations have been introduced to assure each year an adequate number of spawners. These regulations limit fishing or define the gear. In general, the resource has been fully used for years. Consequently, each technological advance in fishing efficiency must be matched by regulations reducing the effectiveness of the gear. A paradoxical situation is produced but such seems inevitable in view of the biological facts and the accepted policy not to refuse fishing privileges to any citizen.

Regulations prevent fishing much above tidal influence or, at smaller streams, near the river mouths at all. Such regulations and the fishermen's desire for comfort and efficiency have, during recent years, promoted the use of gasoline-driven boats, replacing rowboats and sailboats. Still more recently competition for fish has led to the use of larger and faster boats so that the fish can be met and caught as they approach the mouths of the rivers. There results an economic balance between the efficiency resulting from access to all of the fish as they approach the fishing grounds and the inefficiency arising from using better equipment than is necessary to do the work. The situation has been encouraged by the increasing market price for fish. When prices fall the point of economic balance may shift so that the use of expensive equipment may become unprofitable. Adjustment is likely to prove very awkward.

Research Attitude

The fisheries resources of Western Canada are the subject of moderately intense research. Research on the wholly marine species (except herring) adapts traditional approaches to the local species and prevailing conditions. As a basis for assuring maximum sustained utilization, information is sought on such matters as migrations, population limits, the factors controlling abundance through year-class variation, factors influencing catchability by modifying shoaling habits, rates of growth, and intensity of the fishery. The objectives and approaches for herring are complicated by the herring's inshore spawning in the intertidal zone and the consequent conviction that the species is subject to economic extinction by overfishing. Full scale experiments to test the effectiveness of protective regulations are in progress.

Most research effort is devoted to salmon. The anadromous habit makes salmon extremely vulnerable to fishing. The determination and provision of the number of spawners required to perpetuate the resource without withholding an unnecessary surplus from the fishery, are major problems whose difficulty is increased by the variations in reproductive success which occur from year to year under natural conditions in the freshwater habitats of salmon. The parts played by droughts, freshets and frost in suppressing salmon populations are under investigation. Such information is needed both for the determination of the proportion of the runs which should be used by the fishery and for the prediction of variations in the abundance of available fish so that the industry may avoid economic loss through unnecessary surplus of fish on the spawning grounds.

The special hazards which are faced by anadromous fish as a result of human activities have been mentioned previously. Perhaps the most serious interference with natural conditions is produced by hydro-electric developments which intrude impassable barriers to upriver salmon, pass practically all of the water through their turbines, and create great new lakes in their storage reservoirs. Much effort is being put on studies of methods to guide upstream and downstream migrating salmon past obstructions. Culturing in coastal lakes or special nursery areas may prove necessary and the conditions controlling survival are being studied with that in mind. As hydro-electric power is in increasing demand, there is a great sense of urgency in the researches which seek means for preventing the destruction of the salmon fisheries.

POISONOUS FISHES AND THEIR RELATIONSHIP TO MARINE FOOD RESOURCES IN THE PACIFIC AREA *

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Introduction

Recent declines in fish catches in certain regions in the Pacific have stimulated scientific organizations to investigate ways and means of developing latent fishery resources. Other fishing grounds are being explored, and the addition of new fish species to the consumers' menu is being considered. The decline in catches becomes even more serious when considered in the light of increasing human population throughout the world. This increase is estimated to be progressing at the rate of 1 to 1.25 percent per annum, or in terms of numbers, about 25 million people a year. Unfortunately, the population increase has not been matched by the production of food stuffs. Many of the southern Asiatic countries, which prior to World War II were exporters of food stuffs, have since become importers.

Increases in population, decreased food production resulting from political and military upheaval, and the general decline in fish catches have all contributed toward making protein food stuffs a subject of concern. It is not unusual, therefore, that economists should focus their attention on the almost untapped protein food reserves of the sea. However, the development of the shore fisheries of the tropical Pacific will present important problems regarding the edibility of certain fish species which fisheries and public health organizations must not ignore.

Economic Significance of Poisonous Fishes

The economic significance of poisonous fishes can probably be more readily appreciated by reviewing a few instances which have occurred in the tropical Pacific within the last ten years. According to Mr. P. F. D. Palmer,[1] who has managed the Fanning Island Plantations Limited (Line Islands) and has been a resident of the island since 1936, poi-

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sonous fishes (exclusive of puffers) were unknown prior to World War II. Fishes of all types were commonly eaten and supplied to the native workers for their main source of protein. Between February 1946 and April 1947 there were 95 cases of fish poisoning amongst the population of 224 people on the island. A clinical account of these outbreaks has been published by Ross.[2] Palmer further states that from 1946 to 1950 there were "hundreds" of cases of poisoning resulting from the very same species of fishes which they had formerly eaten without ill effect. The problem finally reached the point where feeding their native personnel became critical. Fortunately most of the pelagic species, mullet and some of the lagoon fishes remained edible. Within the last year or two the situation seems to be improving and some of the species have been placed on the edible list again.

A report received from Dr. Vernon Brock, Director, Division of Fish and Game, Board of Agriculture and Forestry of the Territory of Hawaii,[3] indicated that more than 60 tons of red snapper (*Lutjanus* spp.), ulua (*Caranx* spp.) and miscellaneous reef fishes were shipped to the Honolulu fish markets during the years 1930 to 1937. During this time not a single outbreak of fish poisoning was known to occur as a result of eating these fishes. Since the year 1944 scores of outbreaks have resulted from eating Line Island fishes. Some of these outbreaks have been reported by Lee and Pang.[4]

As a direct result of these epidemic unfavorable publicity has developed regarding Line Island fishes. Species such as red snapper (*Lutjanus gibbus, L. vaigiensis, L. bohar),* manini (*Acanthurus triostegus),* grouper (*Epinephelus* spp.), seabass (*Variola louti*), ulua (*Caranx* spp.) and others, are no longer permitted to be imported from the Line Islands and sold in the Territory of Hawaii. A situation such as this results in both fishermen and consumers refusing to have anything to do with fishes coming from a poisonous fish zone.

During the period September 1950 to July 1953, field studies were conducted by our organization in the Phoenix, Line, Hawaiian, Marianas, Eastern and Western Carolines, Johnston, Okinawa, Japan, Galapagos, Cocos, La Plata Islands, the Gulf of California and Panama Bay. Studies thus far indicate that the poisonous fish population of the tropical Pacific is much larger than was formerly believed. Toxic species have been found to occur in the Pacific from the Galapagos Islands to the Philippines and Okinawa, and from Midway to the Society Islands. The survey at Canton demonstrated that about 27 percent of the reef fishes were toxic. The survey at Johnston Island indicated that about 75 percent of the species tested were poisonous. Once an area has established a reputation it is very difficult to change public opinion. As

new fishing grounds are entered and the spectrum of food fishes broadened, public acceptance will be one of the factors determining the success of the venture. A few epidemics can have disastrous effects in a struggling industry, resulting in enormous financial losses and wanton waste of valuable fisheries resources. With the present trends in world population and food supply we can ill afford waste of any food resource and particularly those supplying protein.

Results of Survey Studies

The following report is based upon the field investigation previously mentioned. Table I consists of a compilation of families of fishes which have been incriminated in human intoxications, animal feeding and inoculation tests. This tabulation was made from 574 case histories and technical reports. Cases resulting from ordinary bacterial food intoxications were not included. In addition, approximately another five hundred reports were received that were concerned with more general aspects of poisonous marine organisms.

Many persons have the erroneous idea that poisonous fishes are restricted to "trash fishes", those species which would be generally unacceptable as food for humans, but such is not the case. Perusal of Table I will reveal that the phylogenetic spread is remarkably broad. Families marked with an asterisk indicate those groups which are generally considered to be of commercial importance by various Pacific peoples. Some of the families listed are fresh-water, European, Asiatic or American, but the bulk are Pacific marine fishes. The list obviously fails to consider a number of important factors, viz., geographical locality, ecological biotope, maturity of the fish, and season of the year. Hence, because a family is listed in this table it does not mean that any or all of the members of that family are poisonous throughout their geographic range.

The problem of recognizing a poisonous plectognath is a relatively simple one, since most of the members of this order adhere to a fairly consistent morphological pattern. Numerous toxicological surveys and case reports by Japanese, Australian and American scientists clearly indicate that most plectognaths are to be regarded with suspicion until proven otherwise.* However, the identification of poisonous non-plectognath fishes presents some very real problems because of a number of unique factors, viz.: (1) Apparently, under the proper environmental

* In Japan and many of the other Oriental nations poisonous puffers are routinely eaten and considered a delicacy. The fishes are prepared in a special manner in order to remove the poison and thus make them safe for human consumption. However, in spite of these precautions, the Japanese Government reports more than 125 deaths a year resulting from the eating of these fishes. During the 10-year period from 1927 to 1937 puffer poisoning accounted for 44 percent of the total food poisonings in Japan and was listed as their greatest single cause of fatal food intoxication.

conditions, any fish-like vertebrate is capable of developing (concentrating or metabolizing—which?) ichthyosarcotoxins which can be lethal to man. (2) Poisonous fishes are widely distributed throughout the torrid zone, and some species are known to occur in temperate and arctic waters. (3) A fish that is a valuable commercial species in one area may be poisonous to humans in another locality. Hence, conclusions derived from an epidemiological survey in one area may have little or no bearing upon the incidence or identification of poisonous fishes elsewhere. Distances of even a few miles may entirely alter the epidemiological picture. (4) The problem is not a static one. Fish species which were once edible and commercially valuable species have within the last ten years become poisonous. The situation which has occurred at Line, Johnston and Midway Islands may be cited as classical examples. There are no valid statistical data whether the over-all incidence of fish poisoning is probably on the increase. (5) There is no correlation between the incidence of toxicity and season of the year in most species. Instances of intoxication commonly occur throughout every season of the year. (6) There is no simple field test whereby a toxic fish can be distinguished from an edible one. A poisonous fish appears in form and action no different than a non-toxic fish.

The question of why a fish becomes poisonous is a difficult one to answer. Numerous theories have been propounded, but few of them harmonize with the field observations. The reader is referred to the works of Gudger,[5] Hiyama [6] and Halstead [7] for a more complete review of these theories. There is no single explanation that will satisfy the entire picture.

Recent studies indicate that ichthyosarcotoxins evolve from a number of different sources and through the interplay of a variety of physiological processes. Hence the term 'ichthyosarcotoxism' is an all-embracing one in which are included a number of different and distinct clinical entities. This is indicated by the symptomatology of humans resulting, for example,* from the European barbel (*Barbus barbus* [Linnaeus]), the Pacific puffer (*Arothron hispidus* [Linnaeus]), the Greenland shark (*Somniosus microcephalus* [Bloch and Schneider]), the bluefin tuna (*Thunnus thynnus* [Linnaeus]), the moray eel (*Gymnothorax flavimarginatus* [Rüppell]), and red snapper (*Lutjanus vaigiensis* [Quoy and Gaimard]), are quite distinct. Nothing is known regarding the origin of the poisons found in fresh-water fishes, such as the barbel, nor in sharks. The histamine-like poisons found in scombroid fishes (tuna, bonito, mackerel, etc.) are believed to be tissue breakdown products, possibly the result of bacterial action. Such fishes as the

* The fishes listed are representative of various groups of poisonous fishes which are capable of producing different types of intoxications.

puffer, moray eel and red snapper are believed to become poisonous because of their eating habits.

The acquisition of poisonous properties by a fish is thought to be derived as a result of herbivorous fishes feeding on poisonous marine algae. Carnivorous fishes would become poisonous by feeding on poisonous herbivores. Controlled laboratory feeding studies have demonstrated that at least one species, *Leptocottus armatus* Girard, the California staghorn sculpin, has the ability to feed on poisonous fish flesh and harbor the poison in various tissues of its body with no apparent alteration in its behavior. Studies are now in progress on this particular phase of the program and will be reported at a later date. This food chain theory has been presented in greater detail in our "Survey of the poisonous fishes of the Phoenix Islands." [8]

Ichthyosarcotoxism in man is frequently confused with various types of bacterial food intoxications. True fish poisoning is in no way related to putrefactive processes, hence the state of freshness of the fish has no bearing on the production nor the potency of the poison.* The chemical nature of these poisons, exclusive of puffer poison, are unknown. Some fish poisons appear to exert a variety of physiological effects which represent the combined action of the different components. Many of the symptoms resemble those produced by such compounds as aconitine, muscarine and curare. Many of the scombroid (tuna-like) fishes produce rather violent histamine-like reactions, which appear to be dependent on the freshness of the fish. On the other hand some of the skipjacks contain neurotoxins which are frequently present in freshly caught specimens.

Japanese scientists have studied tetraodon toxin or puffer toxin in great detail. Tetraodon toxin has been assigned the provisional formula of $C_{16}H_{31}NO_{16}$. It has been isolated as a white hygroscopic powder soluble in water and insoluble in the ordinary organic solvents. It is neither a protein, an alkaloid, nor a protamine. The exact chemical nature and relationship of other ichthyosarcotoxins have not been studied to date. All fish poisons, however, are water soluble and relatively heat stable. Ordinary cooking procedures do not destroy or appreciably alter the potency of the poison.

Clinical Characteristics

Since the Pacific Science Congress is primarily concerned with Pacific research, the discussion of the clinical aspects of ichthyosarcotoxism is limited to the four clinical types of ichthyosarcotoxism commonly recorded for the Pacific area.

* The only exception to this statement is in the case of scombroid poisoning which results from eating inadequately preserved fishes. However, the symptoms are quite different from ordinary types of bacterial food poisoning.

1. *Tetraodon* (*Puffer*) *poisoning*: The causative organism is a puffer, one of the members of the suborder Tetraodontoidea. The symptoms commonly noted are in time frequency numbness of the lips, tongue, tips of fingers and toes, which usually develops within 30 minutes after the ingestion of the toxin. This is followed by nausea, vomiting, headache, dizziness and extreme weakness. Power of speech becomes impaired and dyspnea is marked. Within two hours as a rule, the patient suffers complete paralysis with muscles relaxed, body limp, and inability to speak although conscious. Just prior to death the patient lapses into unconsciousness. Death generally occurs in severe cases within 1 to 24 hours as a result of respiratory paralysis. Mortality rate is estimated to be about 60 per cent. Prognosis is considered to be good if the patient survives the first 24 hours.

2. *Gymnothorax* (*Moray eel*) *poisoning*: The causative source is a member of the genus *Gymnothorax*. Symptoms of tingling and numbness about the lips, tongue, hands and feet usually develop within 20 minutes to 7 or 8 hours after ingestion of the toxin. Nausea, vomiting, laryngeal spasm, aphonia, excessive mucus production, foaming at the mouth, injection of the conjunctiva, paralysis of the respiratory muscles, motor incoordination, violent clonic and tonic convulsions, abnormal deep and superficial reflexes and coma follow in rapid sequence. The mortality rate is estimated to be about 10 per cent.

3. *Ciguatera*: Numerous species of marine fishes are capable of causing this type of poisoning. Tingling followed by numbness usually develops almost immediately or within a period of 30 hours after ingestion of the toxin. Nausea, vomiting, diarrhea and abdominal pain are present in about 75 per cent of the cases. Joint aches, malaise, chills, fever, prostration, headache, profuse sweating, pruritus, metallic taste, generalized motor incoordination, muscular weakness, and myalgia are common. Sensory disturbances are present in most cases, hot objects are interpreted as feeling cold and cold objects as hot or like "electric shock" in typical complaints. Convulsions and severe paralyses are less common. The mortality rate is comparatively low, estimated to be about 2 to 3 per cent, and recovery from severe intoxication is very slow, sometimes taking weeks or months to recover completely from the weakness and myalgia.

4. *Scombroid poisoning*: Members of the genera *Euthynnus* and *Katsuwonus* are common offenders. In rare instances these fishes may produce symptoms typical of the ciguatera type of fish poisoning, but more frequently the clinical characteristics are typical of a violent histamin-like reaction. It is the only form of ichthyosarcotoxism known in which inadequate preservation or freshness of the fish appears to be

a factor in the production of the poison. The symptoms generally develop within a few minutes after ingesting the fish and consist of nausea, vomiting, redness and flushing of the face, engorgement of the soft tissues of the eyes, swelling and cyanosis of the lips, tongue and gums, giant urticaria, severe itching, headache and respiratory distress. The victim usually recovers within eight to twelve hours. The few bacteriological analyses of the fish flesh for human pathogens have been negative. Moreover, the toxin appears to be water soluble and is not destroyed by ordinary cooking procedures. The problem of scombroid poisoning has been discussed in greater detail elsewhere.[9]

Treatment

There is no known specific antidote at the present time. An attack of fish poisoning does not impart immunity. The treatment is purely symptomatic. Gastric lavage and catharsis should be instituted at the earliest possible time. Intravenous 10 per cent calcium gluconate in many instances has given prompt relief while in others it has been ineffective. Victims suffering from moray eel poisoning appear to be particularly susceptible to violent convulsions and may present difficult nursing problems. Since the convulsions are precipitated by noise, rest, quiet and sedation are essential. Paraldehyde and drop ether have been reported to be the drugs of choice in controlling the convulsions. Coramine or one of the other respiratory stimulants are advisable in cases of respiratory depression. Excessive mucus production in the buccal cavity is treated by aspiration and constant turning of the patient. Atropine has been found to make the mucus more viscid and difficult to aspirate, and is not recommended. If laryngeal spasm is present, intubation and tracheotomy may be necessary. Nasal oxygen and intravenous fluids supplemented with parenteral vitamins are usually beneficial. If the pain is severe, opiates will probably be required. Morphine given in small divided doses has been recommended. Cool showers have been found to be effective in relieving the severe itching. Fluids given to patients suffering from the paradoxical sensory disturbance should be warmed. Vitamin B complex supplements are advisable.

Summary

The expansion of commercial fishing interests and the utilization of various species of shore fishes in the tropical Pacific impose upon fisheries and public health organizations an urgent solution to the problem of poisonous fishes. Poisonous fishes are widely distributed throughout the torrid zone, but some species occur in temperate and arctic waters. Poisonous fishes are distributed throughout the entire phylo-

genetic series of fish-like chordates, including cyclostones, elasmobranchs and numerous groups of true fishes. Edible and commercially valuable species in one locality may prove violently poisonous in another area. The pharmacological and chemical properties of most ichthyosarcotoxins are unknown. The poisons are water soluble and are not destroyed by ordinary cooking procedures. Bacteria are not involved in the production of the poison. Ichthyosarcotoxism or fish poisoning appears in the form of different clinical entities. Four clinical types of ichthyosarcotoxism typified by various neurological and gastrointestinal symptoms are known to be endemic to the Pacific area: Tetraodon, Gymnothorax, Ciguatera and Scombroid poisoning. The interrelationship of the various poisons involved is not understood. The treatment of fish poisoning is largely symptomatic. Research is urgently needed on the distribution, biology, ecology and systematics of reef fishes. The problem of poisonous fishes and fish poisoning will become of increasing economic and public health importance in the Pacific area in the years to come.

Acknowledgment

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TABLE I

LIST OF POISONOUS FISH FAMILIES OF THE WORLD

† Acanthuridae—surgeonfishes	14 *	(1)**
† Acipenseridae—sturgeons	4	
Ageneiosidae—catfishes	2	
† Albulidae—ladyfishes	1	
Aluteridae—filefishes	17	(3)
Anarhichadidae—wolf-fishes	1	
† Anguillidae—freshwater eels	2	
Antennariidae—frogfishes	1	
Aplodactylidae—	1	(1)
Ariidae—sea catfishes	5	
Aulostomidae—trumpetfishes	1	
Balistidae—triggerfishes	20	(2)
Batrachoididae—toadfishes	2	
Belonidae—needlefishes	7	(3)
† Bothidae—lefteyed flounders	1	
Callionymidae—dragonets	1	
Canthigasteridae—sharp-nosed puffer	6	
† Carangidae—pompanos	23	(1)
Carcharhinidae—requiem sharks	3	
Cepolidae—bandfishes	2	(1)
Chaetodontidae—butterfly fishes	9	
Chimaeridae—chimaeras	1	
Chonerhinidae—puffers	1	
Clupeidae—herring	17	
Congridae—conger eels	2	
† Coryphaenidae—dolphin fishes	1	
† Cottidae—sculpins	4	(2)
† Cybiidae—Spanish mackerels	3	
† Cyprinidae—minnows	20	(6)
Cyprinodontidae—killifishes	1	
Dalatiidae—Greenland sharks	2	
Dasyatidae—stingrays	1	
Diodontidae—porcupine fish	10	(1)
† Dorosomidae—gizzard shads	1	
† Engraulidae—anchovies	6	(1)
† Esocidae—pikes	1	
† Gadidae—cods	4	(2)
Gasterosteidae—sticklebacks	1	
Gempylidae—snake mackerels	2	
Gerridae—silver perch	1	
Gobiidae—gobies	6	
† Hemirhamphidae—halfbeaks	2	
Hexanchidae—cowsharks	2	
† Holocentridae—squirrelfishes	4	
Isuridae—mackerel sharks	1	
† Katsuwonidae—skipjacks	2	
† Labridae—wrasses	7	(1)
† Lagocephalidae—puffers	29	
Lepisosteidae—gar pikes	2	
Liparidae—snailfishes	2	
Lophiidae—fishing frogs	2	
† Lutjanidae—snappers	28	(4)

Legend:
† Families generally considered of commercial importance to Pacific peoples.
* Number without parenthesis indicates the number of species reported to be toxic within this family.
** Number in parenthesis indicates the number of species of questionable taxonomic validity reported to be toxic within this family.

TABLE I (Continued)

Molidae—molas	1	
† Mullidae—goatfish	6	
† Muraenidae—moray eels	19	(8)
Myliobatidae—eagle rays	2	
Myridae—	1	
Myxinidae—hagfishes	1	
Ogcocephalidae—batfishes	1	
Ophichthyidae—snake eels	5	
† Osmeridae—smelts	1	
Ostraciontidae—trunkfishes	12	(1)
Petromyzonidae—lampreys	5	
† Pleuronectidae—righteyed flounder	2	
† Plotosidae—oriental catfishes	1	
† Pomacentridae—damselfishes	5	
Priacanthidae—catalufas	1	
Rajidae—skates	3	(1)
† Salmonidae—salmon, trout	2	(1)
† Scaridae—parrotfishes	15	(2)
Scatophagidae—	1	
† Sciaenidae—croakers	3	(2)
† Scombridae—mackerels	8	(6)
† Scorpaenidae—scorpionfishes	13	(3)
Scorpidae—halfmoon fishes	1	
Scyliorhinidae—cat sharks	4	
† Serranidae—basses	26	(6)
† Siganidae—rabbit fishes	3	
Siluridae—catfishes	2	
† Sparidae—porgies	16	(9)
† Sphyraenidae—barracuda	7	
Sphyrnidae—hammerhead sharks	1	
Squatinidae—angel sharks	2	
Syngnathidae—pipefishes	1	
Synodentidae—lizardfishes	1	
Tetragonuridae—squaretails	1	
† Tetraodontidae—puffers	34	(16)
† Thunnidae—tunas	4	
Torpedinidae—electric rays	1	
Triacanthidae—	4	
Triakidae—smooth hound sharks	2	
Triglidae—poachers	1	(1)
Triodontidae—	2	
† Xiphiidae—swordfishes	1	
Zanclidae—Moorish idols	1	
Families not determined	7	(7)

Totals:

Families of Pacific commercial importance	38
Reported toxic families	95
Toxic species	518
Questionable toxic species	90

Legend:
† Families generally considered of commercial importance to Pacific peoples.
* Number without parenthesis indicates the number of species reported to be toxic within this family.
** Number in parenthesis indicates the number of species of questionable taxonomic validity reported to be toxic within this family.

SOME ASPECTS OF FISHERIES PROBLEMS IN THE SOUTH PACIFIC AREA

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Fish plays an important role in the life of most inhabitants of the South Pacific area. It is their main source of protein. The Fisheries Conference held in 1952 at Noumea under the auspices of the South Pacific Commission stressed the importance of fish in the diet and pointed out that as land animal protein is not a regular item in the diet of the peoples of the region and as in most territories, social and economic factors limit the possibility of an early or rapid expansion of protein food supplies from livestock, fish is the most accessible and also the cheapest source of animal protein.

In Melanesia, the present consumption of fish is on a lower scale than in Micronesia and Polynesia, where the consumption of fish and other marine products (algae, molluscs and crustacea) seems rather high, though accurate data are not yet available.

A part of the population of the region, and even a great part, are not in a position to obtain fish easily. I am mainly thinking here of the impression that there are great untapped resources available. It is felt of the other islands fish production is often insufficient to cover the needs of the population, chiefly due to seasonal influences.

The enormous acreage of the South Pacific Ocean leads to the impression that there are great untapped resources available. It is felt that the Pacific Ocean is a region where enormous quantities of valuable food are produced, and that we have to do with the problem of the "untaken crop." One may ask if the untaken crop problems such as those in the field of fisheries, sago production, timber production and so on, are not somewhat over-emphasized in modern times. The untaken crops in the world can only contribute to economic development in as far as the harvesting is within economic possibilities.

Though there are still vast acreages of forests in the world, their exploitation is often impracticable for economic reasons. There are a number of rubber producing plants in nature, but their harvesting is not practical, as it is cheaper to leave those resources "unharvested" and to grow hevea rubber.

Mankind has nearly always passed from the stage of collection, of harvesting what was available in nature, to the stage of cultivation; from collecting and hunting to growing and raising.

In fisheries we see the same picture, on the one hand fish catching, the harvesting of what is available in nature, and on the other hand fish culture, or controlled production.

The abundance of fish in the Pacific Ocean and the fact that the largest ocean in the world furnishes food for only a few million people could lead to the idea that there is no need of fish culture in addition to fish catching. But reality seems to point in a different direction. It is a strange fact that the fish production in the South Pacific area is not sufficient to meet the needs of the population. Instead of being a fish exporting region the Pacific islands are importing fish. New Guinea's imports of fish and fish products in 1952 amounted to a quantity of more than 1,744,000 lbs. with a value of nearly £Aust.186,000; the figures for Fiji are 1,748,000 lbs. with a value of £F.154,500; Western Samoa 1,280,000 lbs. with the value of £NZ.46,230; American Samoa 405,000 lbs. having a value of $47,380. Other territories such as Papua, Tonga, New Hebrides, New Caledonia, French Oceania, Gilbert and Ellice Islands Colony and Netherlands New Guinea also have an appreciable import of fish. Although complete figures of fish imports are not available, a rough estimate gives a value of £400,000 Sterling per year for the region. The available figures indicate furthermore that imports are increasing. Thus it seems possible that fish production in the region has not kept pace with the increasing population. It was stated at the Fisheries Conference that coastal populations sometimes abandon fishing and prefer to buy their food, even including fish in tins. Especially the deep-sea fishing (for pelagic fishes) seems to be declining. The report of the Fisheries Conference refers to:

> "A declining interest among the local populations in the conduct of fishing operations at market-fisheries level and sometimes even at subsistence level."

Fish Resources

The resources within the region can be divided into:

(a) marine fisheries;
(b) inland fisheries.

The marine fisheries are generally divided into:

(a) coral reef and lagoon resources;
(b) mangrove and estuarine resources; and
(c) oceanic resources.

The inland fisheries can be divided into:

(a) fish catching in rivers, lakes, swamps and fresh water estuaries;

(b) fish culture in ponds.

Reef fishing is the main source of fish supply. The limited reef area of some islands and the fact that fish stocks on the reefs are isolated within their particular reef systems set a limit to the yield. The Fisheries Conference states:

> "In some localities, in the neighbourhood of concentration of regional population, these resources appear to have been over-exploited and the current harvest is small. These instances include reefs in the neighbourhood of Rarotonga (Cook Islands), Pago Pago (American Samoa), Papeete (Tahiti), Suva (Fiji), and Noumea (New Caledonia)."

The rapid rate of population increase in Polynesia and Micronesia and the deficiency of the diet in the interior of New Guinea make the problem of how to allow for higher levels of fish consumption per head, even more acute. Under such conditions it seems not unlikely that this reef and lagoon source, already over-exploited in some areas, will become more and more deficient in relation to the increasing demands of the future.

The mangrove and estuarine resources are believed to be abundant and relatively unexploited in New Guinea. The Conference report states:

> "It is in mangrove and estuarine areas that the greatest potential for pond culture exists, but in New Guinea and large islands in Oceania the relatively large tracts of land might be expected, with appropriate social and economic change in the lives of the people, to make a contribution of animal protein on a scale which obviously could not be reached by the smaller islands of the region."

Oceanic resources: The development of pelagic fisheries in the open ocean outside the reefs offers the best opportunity for increased fish production, not only for markets within the territories but also for export. There are, however, in this field many unsolved problems due to lack of knowledge of the pattern and distribution of the principal species in these waters. Stocks in abundance sufficient to carry commercial operations have been indicated in equatorial waters north of New Guinea and south of the Caroline Islands. The Fisheries Conference expressed the opinion that most prominent among these re-

sources are the tunas, but there are numerous other species of potential commercial value, such as flying fish, half beaks and mackerels.

The fisheries industry on a commercial basis should go together with a more differentiated community where a group of fishermen could earn their livelihood by catching fish for sale. Such differentiation does not exist to any marked degree. The number of fishermen in the region who earn their livelihood by fish catching, although not known, is very small. Development in that direction requires better processing techniques.

Processing

The Conference stated:

> "The only methods of processing employed in the region are salting, smoking and drying, mostly by crude and primitive techniques. Only small proportions of fish caught are processed."

In the papers submitted to the Fisheries Conference some valuable information on fish processing is supplied. The paper submitted by the Australian Delegation based on a survey of native methods of fish preservation in New Guinea carried out by Mr. K. W. Anderson of the Food and Transport Division, C.S.I.R.O., during April, May and June, 1950, states that the objects of that survey were:

> "1. To evaluate methods at present in use;
> 2. To determine what improved methods might be introduced to increase the storage life of the fish and make it available:
> (a) for smoothing out seasonal fluctuations in supply
> (b) for distributing to inland protein deficient communities."

In summarizing their observations, they state:

> "As far as could be ascertained, the sole method for preservation of fish used throughout the territory was a simple, crude drying over a hot fire."

The paper gives full information as follows:—

> "The extent to which the fish is dried varies somewhat within uncontrolled limits, but can broadly be classified into two groups:—
>
> (a) short term, partial drying, with or without prior cleaning of the fish, giving a product that is relatively soft, probably has moisture content in the range of 40 to 60% and a storage life of one to seven days. This is the technique used in the great portion of the territory.

(b) a more complete drying of cleaned and split large fish or whole uncleaned small fish, down to a moisture content of about 20% where it is hard and dark in colour, but, when protected from attack by insects, probably has an indefinite storage life even under tropical conditions. This latter technique seems confined to the Sepik River area."

The same paper states that:—

"It is clear that in the absence of controllable pond fisheries the preservation of coastal fish as a means of smoothing out seasonal fluctuations in supply and of distributing inland to protein deficient communities with a poor system of communication will initially best be done by the traditional process of salting, drying and smoking in suitable combination, rather than by adopting elaborate processes such as freezing, canning and controlled smoking."

The importance of salt in the improvement of the existing primitive processing techniques was emphasized by the Australian Delegation, who stated that this salt will either have to be imported from Australia or produced by setting up a plant for its recovery from sea water within the territory itself.

Lack of cheap salt and a small market for preserved fish are partly responsible for slow development in Netherlands New Guinea.

Controllable pond fisheries as a means of smoothing out seasonal fluctuations in supply has already been mentioned. The culture of fish in ponds is not unknown to the Polynesian and ponds seem even to belong to the Indonesian-Polynesian cultural sphere. Fish cultivated are the milk fish (Tuamoto Archipelago, Nauru Island, the Gilbert Islands, the Lau Group), whilst the carp (*Cyprinus carpis* L.) was introduced into Fiji fifteen years ago. The Fiji Government initiated pond culture experimentally in 1950 and yields of fish reached 1200 lbs. per acre per year. However, since sewage had been run into the ponds to promote growth of algae, the Fijians would not eat the fish. In other territories also there is a growing interest in pond culture. It is unknown to what extent fish culture in ponds would contribute to a higher fish production in the region and to a smoothing out of seasonal influences.

The lack of information and data on Pacific island fisheries in general was plainly shown and expressed in the papers submitted to the Fisheries Conference. One of the recommendations of the Conference was:

"That periodical and regular compilation and assessment of quantitative and qualitative information on the fishing industries be recognized as essential prerequisites to regional development."

It is still not quite clear what course a short term development in the field of fisheries should take. The necessary basic survey and assessment of the fisheries resources and potentialities of the region is still most essential and urgent.

At its Twelfth Session the South Pacific Commission authorized the appointment of a Fisheries expert for a term of three years, to assist and stimulate fisheries investigation and development in the region, including inland fisheries and pond culture. It is hoped that these activities will contribute to an absolute increase in production and to increased production per head, permitting an improvement of the nutritional value of the islanders' diet.

November 19, 1953

SYMPOSIUM ON MARINE PROVINCES IN THE INDO-PACIFIC REGION

(SPONSORED BY UNESCO)

Convener: Mr. A. W. B. Powell, Auckland Institute and Museum, Auckland, New Zealand.

Secretary: Mr. Inocencio A. Ronquillo, Bureau of Fisheries, Manila.

AWARDEES OF THE UNESCO SUBVENTION

Name	*Address*	*Nationality*
1. Bruun, Anton Fr.	Deputy Keeper University Zoological Museum Copenhagen K—Denmark	Danish
2. Chu, Tsu-yao	Meteorologist, in charge of Research Section Taiwan Weather Bureau 64 Kong Yuen Road Taipei, Taiwan, China	Chinese
3. Clemens, Wilbert A.	Director Institutes of Oceanography and Fisheries University of British Columbia Vancouver, Canada	Canadian
4. Hardenberg, J. D. F.	Head, Laboratory for Investigation of the Sea Passar Ykan, Djakarta Indonesia	Dutch
5. Hidaka, Koji	Professor Geophysical Institute Tokyo University Tokyo, Japan	Japanese
6. Panikkar, N. Kesava	Chief, Central Marine Fisheries Research Station Mandapam Camp, South India	Indian
7. Powell, A. W. B.	Assistant Director Auckland Institute & Museum P. O. Box 9027, Newmarket Auckland, S. E. 1. New Zealand	New Zealander
8. Serene, Raoul R.	Director, Institut Oceanographique Nhatrang, Viet-Nam	French

9. Serventy, D. L.	Senior Research Officer Wildlife Survey Section C.S.I.R.O., Arundale Hall 1 Museum St., Perth Western Australia	Australian
10. Thompson, Thomas G.	Professor of Oceanography University of Washington Seattle 5, Washington U. S. A.	American

PROCEEDINGS

The Symposium was sponsored by UNESCO, organized and convened by Mr. Powell, the Assistant Director of the Auckland Institute and Museum, Auckland, New Zealand. It was alloted one whole day for presentation. There was a large attendance drawn from Zoology, Geology and Botany as well as Oceanography. The rather full programme of fifteen papers was accommodated by mimeographing all papers in full and distributing copies the day before the meeting. This avoided tedious full length reading of contributions and allowed adequate time for discussion after each paper and a reasonable amount of time at the end of the session for general consideration of the topic.

The symposium convened at 9:00 A.M. with Mr. Powell opening the convention by speaking briefly on the manner in which the symposium was to be conducted, the number of minutes to be alloted to each paper, and the scope of the discussions.

The papers were grouped into three categories, namely deep sea, distribution for general areas, and distribution for particular areas. The subjects represented by the fifteen papers embraced algae, plankton, holothurians, bryozoa, mollusca, fishes, and birds.

The first paper read was that of Dr. W. A. Gosline, Hawaii, entitled "The Nature and Evolution of the Hawaiian Inshore Fish Fauna." The paper dealt with the Hawaiian provinces and inshore fisheries in the upper 200 meters of water. He endorsed the Schilders' Hawaiian Province, into which he advocated including Midway and Line Islands. The geography, water temperature, and current systems of the Hawaiian Chain in relation to the evolution and endemism of Hawaiian fishes were discussed.

Mr. Powell's paper, "Marine Provinces of the Indo-West Pacific," outlined the several published propositions for subdividing the area. It was suggested that the 18 named provinces for the Indo-West Pacific advocated by F. A. and M. Schilder (1939) were in excess of practical requirements. It was also suggested that this nomenclature applied mainly to shallow water faunas and that consideration of both deep

sea and pelagic faunas would probably require separate consideration. Both these points were affirmed by other contributions and endorsed by several speakers. Two slides and a full page map were presented. A question in methodology was brought up but it was suggested that it be taken up in the afternoon discussions.

The next paper, "An Outline of the Distribution of Pacific Deep-Sea Animals", was presented by Dr. Anton Fr. Bruun, Denmark. It covered the deep areas at and below 2,000 meters and described the Pacific Abyssal and abysso-pelagic fauna as part of a cosmopolitan deep sea fauna. The suggested subdivisions of the deep sea faunas were (1) Pacific and (2) Atlantic-Indian Ocean from which an Antarctic region may be separable. Slides showing specimens of deep-sea species accompanied the presentation of the paper.

Dr. Rolf L. Bolin, California, on "Deep-Water Biological Provinces of the Indo-Pacific", based his classification on the Archibenthic fish family, *Macrouridae,* which occur within a 200–2,000 meter range. It discussed myctophids and bathymetric fishes as indicators of biological provinces in the Indo-Pacific. Dr. Bolin's suggested provinces were fewer, of larger scope, and were obviously not delimited by the same factors that gave rise to the shallow-water provinces. The author speculated on the existence of other marine biological provinces as indicated by fishes and other marine fauna, but suggested more comprehensive and detailed investigations before drawing conclusions. There was agreement, however, in the recognition of a Hawaiian Province.

Professor Martin W. Johnson of Scripps Institution of Oceanography, in "Some Outlines of Plankton Concentration in the Eastern and Tropical Pacific", dealt with surveys involving marine plankton distribution along this west coast of North America and in some parts of the tropical Pacific. The surveys were made by different scientific institutions in connection with the California Cooperative Sardine Research Program. The discussion related to the constitution of the plankton found in western Indonesia and also that found near the California coast. Discussion follows:

Dr. HARDENBERG: May I ask whether you can tell us about the composition of the plankton?

Dr. JOHNSON: They are mostly edible diatoms, *Rhizosolenia,* and are substantially not dinolagellates or watery planktons as *Salpa.*

Dr. HARDENBERG: In Western Indonesia, there are few diatoms in the plankton. They are mostly *Peridinium* and watery organisms.

Dr. JOHNSON: We need more work on plankton. We should give emphasis to knowing what we are working on.

Dr. HARDENBERG: It is hard to study our plankton due to the great abundance of floating water organisms.

Dr. JOHNSON: The plankton is not worked out seasonally. It is not such in watery plankton. However, near the California Coast, in spring, there is a large volume of plankton.

Drs. Yaichiro Okada and Shizuo Mawatari of Japan, in their paper entitled "Distributional Provinces of Marine Bryozoa in the Indo-Pacific Region", presented a preliminary report on the distribution of the Indo-Pacific bryozoa, tracing geographical isolation and the oceanographical factors responsible for the formation of Bryozoan Provinces in the Indo-Pacific region. They recognize three subregions, the Indian, the Western Pacific and the Central and Eastern Pacific with eight provinces: (1) Ethiopian and (2) Indian for the Indian Subregion, (3) Malayan, (4) Chinese and (5) Papuan for the Western Pacific Subregion, and (6) Hawaiian, (7) Polynesian and (8) Mexican for the Central and Eastern Pacific Subregion. Discussion follows:

Mr. DOMANTAY: In your study of Japanese Bryozoans have you come across species of *Bowersbankia*?

Dr. OKADA: Yes, there are four species found in Japan but these are not mentioned in this paper.

"The Distribution of Polychaetes within the Indo-Pacific Region" by Mr. G. A. Knox of the Canterbury University College, New Zealand, is the first distributional survey of this group for the area. The polychaetes inhabiting the shelves of 24 regions in the Indo-Pacific area were dealt with. Description of the species in the text was supplemented by tables on the distribution and number of species found in each of the 24 regions. Extensive tables are given, an analysis of which points to recognition of the following faunal areas:—(1) Indian, with possibly a separate Arabian Sea region, (2) Malayan, (3) Philippine, including South China Sea, (4) Southern Japanese, (5) Northern Japanese, (6) Hawaiian, (7) Tropical Pacific. This paper was read by Mr. Powell.

Dr. Leonard P. Schultz in his paper, "A New Approach to the Distribution of Fishes in the Indo-West-Pacific Area" presented a grouping of marine ecological habitats. It advanced the concept that the so-called species as named by Zoogeographers are actually composed of two or more species, subspecies or races, each more or less inhabiting subfaunal areas. He considered that too much reliance has been placed upon check lists prepared by ichthyologists with only a local faunal concept and that the nomenclature used often stressed greater differences between faunas actually occurs zoologically. He advocates com-

prehensive revisional work on generic, specific, and subspecific levels. The discussion related to the spawning periods of marine organisms in different areas. It was stated to be all the year round with certain species in tropical Djakarta, March the month for most prevalent spawning of fishes at Palmyra and March, April and May for the Marshall Islands. Comments and discussion follow:

Dr. HARDENBERG: In tropical Djakarta, most species spawn the whole year round. We found two types that breed the whole year round and another type that spawns during the fall and spring only. Are your Carangids more or less related to our species?

Dr. SCHULTZ: Yes.

Dr. GOSLINE: I found that the check list and list of species of fishes of Guam could not be used in the case of the Hawaiian fishes. I also found that the Hawaiian Islands are not coralline, that coral reefs there are very small, with almost no atoll present, and that those parts with cooler waters have different fishes.

Dr. SCHULTZ: You just have to ignore the list of fishes of Guam. Only 50% of it is correct. In one case, 35 species were listed as new but the listing were later found not valid, and this is probably true of other species. In the Samarano, if the ichthyologist cannot describe these, he classifies them as new, as was found in the case of parrot fishes.

Dr. HALSTEAD: I made various studies of coral atolls at various times of the year. In Palmyra I found that March is very definitely the month when the fishes are most active as far as reproduction is concerned.

Dr. JOHNSON: In the Marshall Islands, March, April and May show very heavy spawning in plankton samples. It is probably so in other places.

After the discussion on Dr. Schultz's paper, Mr. Powell announced a recess for refreshments.

The after-recess session began at 11:30. Only one paper, "The Zoogeographical Distribution of the Indo-Pacific Littoral Holothurioidea", by Mr. Jose S. Domantay of the Philippine Bureau of Fisheries, was read. The paper covered the study of the littoral forms of Holothurioidea found at depths not exceeding 50 fathoms. It proposed the zoogeographical division of the Indo-Pacific Ocean based on the Holothurian fauna, into the following ten provinces: (1) North Pacific (2) South Pacific (3) East Pacific (4) West Pacific (5) Northwest Pacific (6) Southwest Pacific (7) Northeast Pacific (8) Southeast Pacific (9) Central Pacific and (10) Indian Ocean. These areas for the

most part fall readily into the named scheme of the Schilder's. He also advanced opinions on the causes for the unequal distribution of the North and South Pacific Holothurian fauna. The number of the different species of the various provinces were tabulated and presented in graphs and charts.

The session adjourned for lunch at about midday.

When the afternoon session resumed at 2:00 P.M. Mr. Powell announced that there were six more papers to be presented. He said that aside from the discussion after each paper, there would be a general discussion after all the papers had been read. Comments and suggestions would be entertained. Mr. Powell then called upon Dr. Hardenberg to read his paper.

Dr. Hardenberg's paper entitled "Distribution of Marine Fishes in South East Asian Waters" presented the general range of distribution of tropical marine fish fauna of South East Asian seas. The complex pattern of the occurrence of fishes in different regions was discussed. It mentioned the division of the seas into regions, and the factors important to the ecology of the marine fauna. Various species were cited for particular fish fauna of several regions with common ecological characteristics.

The discussion was mostly concerned with the location of the eggs and post-larval stages of parrot fishes.

Dr. SCHULTZ: I have been troubled for years about parrot fishes and how their eggs look like. Have you seen some eggs of these fishes?

Dr. HARDENBERG: No. I saw only ovaries with small eggs. I have seen a parrot fish in the open sea.

Dr. SCHULTZ: We are troubled as to the identity of pelagic eggs at Bikini Atoll. They looked like anchovies but these fish are not found there. We even found certain fish eggs that looked like anchovy eggs.

Dr. JOHNSON: I found fish eggs 20 miles from the nearest land.

Dr. SCHULTZ: What is the smallest parrot fish you have found?

Dr. HARDENBERG: The smallest fish I have found is about 20 mm. long. I observed the same condition in *Caesio*. The smallest I have seen is about 5 to 6 cm. long. I have seen *Caesio* spawn at the edge of coral reefs and the larvae get away after spawning.

Dr. D. L. Serventy in "An Analysis of the Pelagic Bird Faunas of the Indo-Pacific Oceans", working on taxonomy in relation to distribution patterns, considered that the whole of the Indian Ocean and the western and central part of the Pacific represented one homogeneous fauna consisting of long-established descendants of the Tethyan fauna of the

Tertiary. He did, however, recognize a sub-speciation centre in the region of the Kermadec Islands. It interpreted the known taxonomic and zoo-geographical facts. Factors regulating the ebb and flow of species movement were analyzed. Faunal elements in the Indo-Pacific region were presented with enumeration of bird species with their habitat and migration. The paper was illustrated with three maps. Dr. Murphy referred to this paper as an admirable review in which the author reached a series of conclusions in harmony with the known geological history and without resource to hypothetical land gaps or land bridges. Discussion follows:

Dr. Murphy: Dr. Serventy's study is more admirable than that review it indicates. He found the breeding grounds of the sea bird species not familiar to the audience. He built up a series of conclusions which then coincides and harmonizes with the groups of sea birds and the geological history. He needed no land gaps and land bridges.

Mr. Tubb: I would like to ask about the flying habits of the frigate birds. I have observed those that circle up to the point of invisibility and, when very high, cross the country where they roost. Boobies are also seen from land when nesting. They fly direct to waters near the nest.

Dr. Serventy: I am glad to know that frigate birds cross land and that they fly far from roosting islands. I have not seen this in the literature.

Dr. Hardenberg: I wish to confirm the statement of Mr. Tubb concerning the flying habits of the frigate birds.

Dr. Wooster: When we were opposite Cape Monticino, a bird stayed on our ship for three hours when we were about 1,500 miles from land. I would like to know if petrels form colonies.

Dr. Serventy: There are big scale conditions where petrels form colonies, that is, from South America to California. There in a random collection of birds we could recognize the New Zealand birds, and other sea birds were presented. There is no evidence, however, of migration of sea birds in historic times.

Dr. E. Yale Dawson's paper, "Some Distribution Patterns Represented by the Marine Algae of Nhatrang Bay, Vietnam", was read by Dr. Maxwell S. Doty. It presented a brief picture of the present knowledge of the marine algal flora of Indo-China. Results of the algal study undertaken by the author on the distribution of the different species and their occurrence were presented. The paper also presented two generalities on marine algae of the Indo-Pacific; namely, the outstanding deficiency of information about algae not only of the South

China Sea but also of the whole Indo-Pacific region, and local variations in ecology as the cause for the extreme diversity between algal associations of adjoining localities.

The paper, "Some Problems on Marine Biogeographical Micro-Provinces Surrounding Japan", by Tadasige Habe, Tokubei Kuroda, and Denzaburo Miyadi was read by Dr. Okada. It points out that in southern Japan cold water continental coastal faunal elements often survive in bays whereas the adjacent open coast may have a warm water fauna belonging to a different marine province. Stress was made on the idea that biogeography based on taxonomic differences is only one side of biogeography. A comparison of bay fauna with littoral fauna of the open sea, with specific examples of various species, was presented. Several authors interpreted the term biogeographic provinces in the ecological or zonation issue and this led to some discussion. The characteristic aspects of marine littoral fauna which bear on biogeographical segmentation of Japanese seas were discussed.

The paper of R. K. Dell of the Dominion Museum, New Zealand, entitled "The Marine Mollusca of the Kermadec Islands in Relation to Molluscan Faunas in the South West Pacific", came next and was read by Dr. Hiatt. It reviewed briefly the literature on the marine mollusca of the region and the author's own findings in his investigations of the different species and genera.

"The Geographical Variation of Early Embryonic Processes in Marine Eggs" was read by Dr. Alexander Wolsky, Principal Scientific Officer of Unesco in South East Asia. It dealt with the different factors affecting the development of marine eggs, and the causes of geographic variation in the embryonic processes. Dr. Boschma commented on the paper.

Dr. Boschma: I agree with Dr. Wolsky that some species of animals found in the North Sea and in the Mediterranean have differences in their development. The study of their embryos must be interesting.

After this paper had been read, Mr. Powell opened the meeting for general discussions.

Dr. Bruun: We found some Actinians in the Philippine Deep and also in the Java Trench. I believe that this form is endemic in the trenches. We also found more in the depth of 6,000 meters, which cannot differ much from those found in the deep waters of India and Japan. As shown by the work of Dr. ZoBell, the bacteria for the Philippine Trench die when subjected to a pressure of 800 atmospheres, while they live at a pressure of 1200 atmospheres. It

is possible that the deep sea fauna can be split according to differences in pressure, i.e. variation in pressure at the slopes rather than differences in temperature.

Dr. Gosline: I found that the fishes in the high island are similar to those found in the coral reefs and in the low islands. However, I found that in high islands with low water temperatures the species of fishes are poorer.

Dr. Schultz: I have noticed the relationship of fishes in the different provinces. As the distance gets farther for wide ranging species, there is a considerable difference in morphology and color distinctions. In different fish populations the colors vary widely. For example with reference to eels the use of the color for differentiation is very difficult to apply in the field.

Dr. Panikkar: It is interesting that prawn is marine in the Mediterranean but is estuarine in India and fresh water in China and Japan. They belong to the same species but differ physiologically. Another example is *Arenicola,* which was recently found in the Gulf of Bombay.

Dr. Hiatt: I hope that we are not confusing here ecological conditions and biological distribution. We may find new arrivals of animals in certain localities but we should not discuss these animals imported by men, i.e., those that had not existed in that locality before.

Dr. Harry: I observed that the faunas in the Atoll area are different from those in Hawaii, i.e., where the land shelf drops fast, and that similar atolls have similar fishes.

Dr. Bolin: Rough shore and sandy beaches are different. Differences in habitat in a biological province are not so important but the similarities of fauna in high island and coral atoll are important.

Mr. Powell: This symposium stimulates more interest along the line of biogeographic distribution. Gentlemen, we have to conclude this part of the session. When I say this part of the session, I am referring only to the official presentation on the subject today, for I am sure sufficient materials have been presented today to be the subject of wide and lengthy discussions for a long time to come, and I am very thankful indeed to all of you for your splendid response to this symposium which I had the great pleasure of organizing. Thank you very much.

The symposium adjourned at 4:30 in the afternoon.

THE NATURE AND EVOLUTION OF THE HAWAIIAN INSHORE FISH FAUNA[1]

By William A. Gosline
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Introduction

A very large number of the shallow-water animals of the Hawaiian Islands are endemic, and the area is usually considered a major zoogeographic subdivision of the great, marine, shallow-water, Indo-West-Pacific region (Ekman, 1953). Among Hawaiian species of inshore fishes estimates of endemism range between approximately 15% (Fowler, 1928) and 50% (Jordan and Evermann, 1905). In my opinion the latter figure is about correct. Neither the distinctiveness of the Hawaiian inshore fish fauna nor its derivation from an Indo-West-Pacific stock are in doubt, and these matters will not be discussed here. The purpose of this paper is to present a preliminary analysis of the factors that appear to have brought about the present status of the Hawaiian shore-fish fauna. It is based on five years of investigation and on collecting trips to Johnston, Wake, and most of the Hawaiian Islands. Nevertheless, present knowledge is insufficient to provide more than leads to the subject, and no help is to be obtained from other components of the Hawaiian shore fauna, for they are more poorly known than the fishes. Consequently the ideas presented here can deserve no rating higher than that of working hypotheses.

Geography

The Hawaiian Islands (Fig. 1) form a long, narrow chain extending for some 1600 miles along a southeast to northwest axis. Hawaii, at the southern end of the chain is the largest island in the central Pacific, whereas Kure, at the opposite end, is the northernmost coral atoll in the Pacific. The greatest distance between any two islands in the chain is less than 200 miles. For zoogeographic purposes, Johnston Island (Fig. 1), about 450 miles to the south of the central part of the chain, must be considered an outlying component of the Hawaiian faunal area.

The nearest shallow waters to the north and east are those of the Aleutians and Alaska, somewhat less than 2000 miles away. Between

[1] Contribution No. 49, Hawaii Marine Laboratory in cooperation with the Department of Zoology and Entomology, University of Hawaii.

Hawaii and the mainland United States lie about 2000 miles of deep water. There are no shallow-water fishes common to the Hawaiian Islands and the shores of North America, though a few high seas species, e.g., the albacore, inhabit both regions. To the south of the United States, America slopes away from Hawaii, so that the distance from Hawaii to Panama is about 4000 miles. Thus the nearest American coasts with water temperatures similar to those of Hawaii are separated from that island by at least 2500 miles of deep sea. The Hawaiian fish fauna has derived little or nothing from tropical American waters.

The nearest shallow-water areas to the Hawaiian chain lie to the south and west. The Line Islands (Fig. 1) south of Honolulu extend to within about 850 miles of Hawaii and to 800 miles southeast of Johnston. Due west of Hawaii, Wake (Fig. 1), a northern outlier of the Marshalls, lies about 1200 miles southwest of Midway (and about half way between Honolulu and Japan).

Water Temperatures

With regard to surface-water temperatures, it can be seen from Table I that all of the islands of the Hawaiian chain, Wake, Johnston, and Palmyra (in the northern Line Islands) have about the same temperatures in summer; there is, however, considerable difference between the northern parts of the Hawaiian chain and the other islands mentioned in winter. Since the Hawaiian fish fauna is essentially a tropical one, it would seem probable that if any temperatures are critical for Hawaiian fishes, they are those of winter. Consequently summer temperatures will be dismissed from further consideration. In winter, the differences in water temperatures within the Hawaiian chain are greater than those between Hawaii and the northern Line Islands or Wake.

TABLE I

Surface Water Temperature (from Sverdrup, Johnson, and Fleming, Charts II and III)

	February		August	
	Temp. C.	Difference	Temp. C.	Difference
Wake	25		28	
		7		2
Midway	18		26	
		6		0
Hawaii	24		26	
		1		1
Johnston	25		27	
		1		0
Palmyra	26		27	

If cold water were the principal limiting factor in the differentiation of Hawaiian shore fishes, then greater variation would be expected within the Hawaiian chain than between the northern Line Islands or Wake and Hawaii. This, however, does not occur. On the contrary, the fish fauna throughout the Hawaiian chain seems to be quite homogeneous. Except for slight indications of racial differentiation in two species (*Kuhlia sandvicensis* and *Istiblennius zebra*), attempts to distinguish even races of fishes within the Hawaiian chain have been unsuccessful.

As to number of species, there are several *a priori* reasons for suspecting that it might differ at the two ends of the Hawaiian chain. One is the great differentiation in winter water temperatures within the chain noted above. A second is that the southeastern islands are high and volcanic, whereas the northwestern are low coral atolls. Presumably all the atoll habitats are present around the high islands; however, the volcanic rock habitats of the eastern islands are absent from the whole western part of the chain. Finally, there is the possibility that the low western islands have a larger fauna because they are older. Unfortunately, it is impossible to say whether the number of species at the two ends of the Hawaiian chain actually does differ, for the low leeward islands have been very poorly collected and the absence of species records from these islands means nothing. Consequently, it becomes necessary to fall back on general impressions for what they are worth. After collecting at most of the islands from Hawaii to Midway it is my personal feeling that there is a decrease, though probably not an evenly graded one, in the number of species from southeast to northwest. Indeed I have collected no species in the leeward islands that I had not already collected in the high Hawaiian islands. (On the other hand the number of individuals of a species seems to increase from south to north. Also, judging from a few non-commercial species, the maximum size of individuals within at least some species increases from south to north.) If, however, there are species on the high islands restricted to lava rock habitats, I do not know them. In Oahu, the great majority, at least, of the species found over lava rock may also be encountered over coral or coralline limestone areas. It seems necessary then to fall back on winter temperatures as the cause of the decrease in number of species in the leeward group, if indeed such a decrease really takes place.

Current Systems

The adults of most Hawaiian inshore fishes are bottom feeders that would presumably starve in the open sea. It is generally believed,

though by no means verified, that most such fishes arrived in Hawaii as planktonic larvae carried in by the ocean currents. Under such postulates the current systems should play a dominant role in the development of the Hawaiian inshore fish fauna.

However, there seems to be little correlation between the present current systems of the Hawaiian region and the fish immigration routes. Although the Hawaiian inshore fish fauna has come in from the south and west, there are no known northeasterly-flowing currents reaching the Hawaiian Islands (see Sverdrup, Johnson, and Fleming, 1942, Chart VII). The North Equatorial Current, in which Hawaii lies, flows toward the west, and the eastwardly flowing Equatorial Counter Current does not pass within 800 miles of these islands. If the derivation of the Hawaiian inshore fishes is to be tied in with present current systems there would seem to be only two possibilities, both in my opinion rather remote. One is that the larval forms were carried to the east of Hawaii in the Counter Current and then doubled back in a great eddy of the North Equatorial Current that carried them over 800 miles north. The other is that Hawaiian fishes were carried in to Kure and Midway from the Bonins and Japan by a southern tongue of the Kuroshio Current (see Sverdrup, Johnson, and Fleming, 1942: 122). This would involve transport in a slowly moving current across more than 2000 miles of deep water.

There is of course the possibility that the current systems of the Hawaiian area were different in the Pleistocene than they are today. However, Arrhenius (1952) has shown that there was little or no displacement of, at least, the Equatorial Counter Current during the Pleistocene.

If the immigration of Hawaiian fishes took place randomly, e.g., via occasional eddies within the major current systems, then it would seem logical that they came in from the nearest islands, namely, Johnston and Wake. There is indeed considerable evidence in the Johnston fish fauna that this island has formed something of a way point in both the immigration and emigration of Hawaiian fishes.

Nature of the Hawaiian Fish Fauna

Before treating the endemism among Hawaiian fishes it seems advisable to divide these into several ecological categories. First, there are a small number of Hawaiian fishes, mostly gobies, that have taken up a primarily fresh-water existence in the streams of the high islands. At the other end of the scale are the deep-water fishes, both bathypelagic and bottom dwelling forms. Third, there is a group in which the adults are pelagic, e.g., most sharks, the tunas, flying-fishes, and

Schindleria. All three of the above-mentioned groups will be omitted from further consideration in this paper. The remaining, inshore fishes will again be divided into two categories for purposes of treatment here. One group contains those species ordinarily living in depths of approximately 200 to 600 feet, and the other those fishes usually inhabiting depths of less than about 200 feet.

Of those fishes living between 200 and 600 feet, relatively little is known. In Hawaii there is a considerable hand-line fishery for such species, but only the larger forms are taken, and of these only the edible forms are brought in. About all that can be said of this group is that it seems to show less endemism and a greater affinity to the Japanese fish fauna than is present among shallower-water forms.

The rest of this paper will be devoted to those fishes usually living in less than 200 feet of water. This inshore group is not only the best known, but contains well over half of all the fishes recorded from the Hawaiian Islands. Four main features must be noted about these forms. First, a large proportion of the Hawaiian species appear to be endemic. Second, at most a very few of the Hawaiian genera are endemic. Third, the Hawaiian inshore fish fauna, in distinct contrast to the Hawaiian terrestrial biota, is a harmonic (balanced) one. Finally, the Hawaiian fish fauna does not appear to be a particularly impoverished one by Central Pacific standards.

It is necessary to discuss each of the above points in some detail. Since the lack of endemic genera and higher categories is most easily dismissed, it will be dealt with first. There are, to my knowledge, only two genera of Hawaiian shallow-water fishes (*Gregoryina* and *Microbrotula*) that can be considered endemic. However, both of these are made up of small, rarely collected forms that may have been overlooked elsewhere.

The statement that a large proportion of Hawaiian inshore species of fishes are endemic needs some qualification, for the question may be raised whether the Hawaiian endemics are not merely subspecies. Indeed it cannot be proved that these endemics will not and do not interbreed with their central Pacific counterparts (see below). Nevertheless, there are two basic reasons for considering the Hawaiian endemics as full species. One is that the Hawaiian representatives of an Indo-Pacific Artenkreis are usually better differentiated than any other populations of the Artenkreis, e.g., *Acanthurus sandvicensis* in the *A. triostegus* complex (Schultz and Woods, 1948). The other and more important reason is that no intergradation can be demonstrated at the borders of the ranges between the Hawaiian and the central Pacific forms. Johnston and Wake (Fig. 1) are both islands which geograph-

ically lie somewhat between the Hawaiian and central Pacific faunal areas, and a mixture of these two faunas (but with a high predominance of Hawaiian forms) is found at Johnston. Nevertheless, no intergradation between the Hawaiian endemics and their central Pacific counterparts was found at Johnston. Among four species complexes investigated in some detail (*Muraenichthys cookei- laticaudata, Gymnothorax eurostus-buroensis, Acanthurus sandvicensis-triostegus* and *Kuhlia sandvicensis),* the Johnston populations of the first three represented the pure Hawaiian stock, and of the fourth the pure central Pacific form. In no instance were *both* the Hawaiian and the central Pacific forms found at Johnston, nor have they been found together elsewhere.

As to the harmonic nature of the Hawaiian fish fauna, a very high proportion of the families and genera of shore fishes found in the central Pacific east of Samoa have representatives in Hawaii. There are, however, two notable and curious gaps in the Hawaiian shallow-water fish fauna. Throughout most of the tropical Pacific, two of the most prominent genera are *Lutjanus* and *Epinephelus.* In the northernmost of the Line Islands, for example, perhaps a half dozen species of each of these genera occur. In the Hawaiian Islands and Johnston *Lutjanus* appears to be totally unrepresented, and *Epinephelus* occurs only in a single, deep-water form. Yet the families to which these two genera belong are abundantly represented in Hawaii by other, smaller, deeper-water genera. These gaps seem especially peculiar in that both genera are made up of generalized, moderate to large sized fishes. Furthermore, both are present in Japanese waters that would seem to be colder than those of Hawaii.

With regard to the relative size of the Hawaiian fish fauna, little can definitely be said. On the one hand numerous central Pacific species are unrepresented in Hawaii. On the other, more inshore species are recorded from Hawaii than from any one central Pacific island group east of Samoa. However, except for Hawaii, no central Pacific island group east of Samoa has been adequately collected. Under any circumstances the Hawaiian inshore fish fauna, with some 400–500 known species, cannot be called depauperate.

Characteristics of Hawaiian Endemic Fishes

The characteristics by which Hawaiian endemic fishes differ from their ancestral forms, i.e., their central Pacific representatives, can best be treated under two categories: physiological and morphological. In morphological features the Hawaiian endemic fishes show no pattern of divergence from their central Pacific relatives. One Hawaiian endemic has a greater number of fin rays; a second has fewer gill rakers; a third has the dorsal fin originating farther forward; a fourth has

slightly longer jaws; a number differ in various details of color pattern; etc. Even within a family no trend of divergence is shown by the various Hawaiian endemic members. Consequently there seems to be no possibility of correlating the morphological peculiarities of Hawaiian endemics with distinctive features of the Hawaiian environment, e.g., colder water temperatures. One anticipated correlation of this sort is strikingly absent: Hawaiian coral reefs are notably dull colored as compared with those of the central Pacific, yet the fishes seem to be as brightly pigmented as those to the south. It is not, therefore, easy to escape the inference that the morphological peculiarities of Hawaiian endemic fishes are *per se* non-adaptive.

Treatment of physiological differentiation is handicapped by the fact that almost nothing is known of the physiological reactions of tropical marine fishes. It might be expected that Hawaiian fishes have become physiologically adjusted to life in colder waters than their more tropical ancestors. There is some indirect evidence for, and none against, this supposition. The best available bit of information in this connection is derived from the spawning seasons of certain Hawaiian fishes. One would expect (Ekman, 1953: 113) that a tropical species living in Hawaii would spawn, at least primarily, during the summer months when water temperatures most closely approximate those of its ancestral home. However, many Hawaiian fishes spawn primarily or entirely in winter at temperatures below those ever reached in more tropical regions. One example will suffice. Around Honolulu *Pomacentrus jenkinsi* spawns from December to March; no ripe females have been taken during the remaining months. At Arno, 10° nearer the equator in the Marshalls, Dr. Strasburg informs me that ripe females of this same species were taken in July. (Hawaiian specimens of *Pomacentrus jenkinsi* do not seem to be morphologically distinguishable from their central Pacific counterparts, which further emphasizes the advisability of treating the morphological and physiological peculiarities of Hawaiian forms separately.)

The restriction of spawning in *Pomacentrus jenkinsi* (and other similar examples can be given) to winter around Oahu is the reverse of what would be expected, and the explanation for this phenomenon is obscure. Perhaps the Hawaiian populations of *P. jenkinsi* have at one time become adapted to waters even colder than exist around Oahu today, e.g., in the Pleistocene, and the winter spawning is merely a holdover from such adaptation. (In any event, the Hawaiian fishes must either have come in since the Pleistocene, under which supposition it is difficult to explain the high degree of endemism, or they must have been able to survive the Pleistocene water temperatures of Hawaii.)

Causes of Endemism among Hawaiian Fishes

In the preceding sections the nature of the Hawaiian fish fauna has been discussed. It remains, however, to attempt some explanation to the question of why it is as it is. Why, on the one hand, has not the fish fauna undergone the adaptive radiation found in the Hawaiian terrestrial fauna (see Zimmerman, 1948)? Why, on the other hand, is there any endemism among Hawaiian fishes at all?

The answer to these questions would seem to be found in the degree of isolation of the Hawaiian Islands. Though the Hawaiian chain is equally isolated in space for both fishes and terrestrial organisms, the fishes (and other marine organisms) seem far better adapted to getting there than most terrestrial forms. This is immediately indicated by the balanced nature of the fish fauna as compared with the terrestrial biota. Indeed there are a large number of central Pacific fishes unrepresented in Hawaii, but on the whole it looks more as though such absences were due to unsuitable conditions for survival rather than to inability to arrive there.

If the foregoing is correct, most or all suitable inshore environmental niches have been filled by immigration, and the possibility of an adaptive radiation among Hawaiian fishes is precluded. But also, if the foregoing is correct, the question of why there is any endemism at all among Hawaiian fishes becomes difficult to answer.

In my opinion, the endemism among Hawaiian fishes has been brought about by two factors acting together and, in general, additively. The primary cause is a moderate degree of isolation. The secondary cause is the slightly colder water of the Hawaiian Islands as compared with the tropical central Pacific.

With regard to isolation, it has been stated above that the vast majority of central Pacific fishes have probably arrived in Hawaii at one time or another. By this it was not meant that the Hawaiian fish population is deluged by an influx of immigrants every year, but rather that one or a small number of specimens of most central Pacific species have managed to get to the Hawaiian chain from time to time. Presumably the original entrants, if they survived and reproduced, would have had time to saturate the islands with their descendants before the next immigrants arrived. There is some evidence that such a process does take place. As already noted, at Johnston the pure central Pacific stock of *Kuhlia sandvicensis* is represented, but among three other fishes the pure Hawaiian form is present. Apparently what has occurred is that in the case of *Kuhlia* the central Pacific stock has been able to saturate the island with its representatives. Subsequent immigrants from Hawaii were either unable to survive at Johnston, or if they

survived and interbred with the central Pacific form they did so in such relatively small numbers as to leave no trace of intergradation on the Johnston population. For the other three fishes the situation would seem to be similar except that the Hawaiian form has either arrived first or totally displaced the central Pacific type.

The original immigrants to Hawaii that gave rise to the descendant population may or may not have been aberrant members of the ancestral stock. Furthermore, during at least the initial increase in the population, random drift may have been effective. Finally, among Hawaiian fishes, these possibilities of aberrant initial immigrants and random drift may have occurred at least twice, once at the stepping stone of Johnston (or possibly Wake) and again on first arriving in Hawaii.

The above factors (more fully treated in Zimmerman, 1948: 122-125) may have caused differentiation through isolation *per se*, and this differentiation would be of a non-adaptive type. Once arrived in the Hawaiian Islands the fishes may have undergone further differentiation in adapting themselves to the colder waters of this area. (Evidence for one such adaptation has already been discussed.) Such adaptive physiological differentiation would increase the ability of the residents to compete with further immigrants, so that these would be able to pass even fewer genes into the resident population than before (providing of course that they could interbreed at all). Consequently, I believe that the integrity of a Hawaiian endemic species has been maintained whether or not an occasional central Pacific immigrant has interbred with it, and that the physiological adaptations of the endemics have insured them from extermination through competition with the central Pacific immigrants that may have arrived subsequently.

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FIG. 1.—The Hawaiian chain and the islands nearest to it. Land areas greatly exaggerated in size.

MARINE PROVINCES OF THE INDO-WEST PACIFIC

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The precise definition of shallow-water provinces in the tropical Indian and Pacific Oceans is difficult since accurate faunal lists are few, not many bibliographies have been published, and the systematics of only a few groups are adequately known.

The purpose of this paper is not to present a scheme based upon the systematics and biogeographic data of one phylum (mollusca) but to invite discussion of the topic by workers representative of as many phyla as possible.

If a working plan satisfactory to the majority of interests emerges from this discussion it is hoped that agreement may be reached regarding both the nomenclature and the respective boundaries of any approved provinces.

It is realized that provinces apparent in the littoral do not necessarily extend to the deep waters, not even to the continental shelf in all instances. The abyssal faunas probably bear no relation to the shallow-water faunas and will require separate consideration. Pelagic faunas also will probably require special treatment.

The recent appearance of Ekman's "Zoogeography of the Sea" (1953) will undoubtedly cause a renewed interest in biographic studies. Ekman's classification of the tropical faunas is as follows:

1. *Indo-West Pacific.* Indian ocean to 30–35°S and the western part of the Pacific between 35–40°N and 30–35°S; extending from the east coast of Africa to the Hawaiian, Marquesas and Tuamotu Islands.
2. *Atlanto-East Pacific.*
   A. Tropical and Subtropical America
      a. Pacific American warm water region.
      b. Atlantic American warm water region.
   B. Tropical and Subtropical West Africa.

We are concerned only with the Indo-West Pacific which Ekman subdivided into—

1. Indo-Malayan, 2. Islands of the Central Pacific (excluding Hawaii), 3. Hawaii, 4. Subtropical Japan, 5. Tropical and Subtropical Australia, and 6. Indian Ocean.

Recognition of the Indo-West Pacific as a homogeneous faunal region is irrefutable. To this region alone is confined all the Recent sea snakes. Of the 46 Recent species of the coral *Fungia* only one is found outside the region. Among living molluscs *Nautilus, Hippopus, Tridacna* and *Malleus* are not found elsewhere. Without mentioning specific instances Ekman (1953) refers to many coral and alcyonarian families confined to the Indo-West Pacific, and Myers (1940) recognises many families and genera of fishes not found outside this region.

The outstanding paleogeographic condition that gave rise to this vast faunal region was undoubtedly Suess' Tethys Sea which allowed almost unimpeded dispersal in the tropical zone. This sea is known to have persisted with but brief local interruptions from the Lower Cambrian to the Tertiary.

The recognition of the influence of this vast waterway readily dissolves many otherwise anomalous cases of discontinuous distribution. In molluscs, for instance, the spread to the Austro-Neozelanic provinces in the Tertiary of characteristic Paris and Vienna Basin genera (Eocene-Miocene), such as *Baryspira* and later *Pecten* and *Ranella,* is noteworthy.

Although the segregation of faunas within the Indo-West Pacific must be of late development a fairly clear segregation is even now apparent with endemism strongly marked in areas of continental origin as opposed to the oceanic faunas of islands of coral or recent volcanic origin.

A false impression of uniformity in the molluscan faunas of the widely scattered insular areas of the Indian and Pacific oceans is given by the extensive distributional patterns of common species of spectacular appearance; i.e. the spotted cowrie *Cypraea tigris,* and the spider-shell *Lambis lambis.*

In many unrelated tropical gastropod families two efficient free-swimming larval types, known respectively as Sinusigerid and agadinid, are characteristic of most of the Indo-West Pacific wide ranging species.

It is therefore among the sedentary and less conspicuous elements that endemism is apparent and in the mollusca in particular many regional species and subspecies are apparent.

Ekman's six divisions of the Indo-West Pacific are in my opinion conservative, and on the other hand the eighteen divisions advocated by F. A. Schilder and M. Schilder (1939) on the basis of a world survey of the Molluscan family Cypraeidae are certainly excessive. Ekman made no reference to this work in his "Zoogeography of the Sea."

The Schilders advocated the division of the Indo-West Pacific into three "provinces" and eighteen "regions". Their terminology should be reversed of course, i.e. "province" = subregion, and "region" = province.

The scheme is as follows:—

A. INDIAN PROVINCE.

1. Erythraean Region. Red Sea.
2. Persian Region. Persian Gulf to Karachi.
3. African Region. Somaliland to Mozambique and Southern Madagascar.
4. Lemurian Region. Northern Madagascar, Reunion, Mauritius, Seychelles and Maldive Islands.
5. Indian Region. India and Ceylon.

B. CENTRAL INDO-PACIFIC PROVINCE.

6. Sumatran Region. Andaman and Nicobar Islands, Sumatra, Christmas Island, Sunda Strait and south coast of Java.
7. Moluccan Region. Bali Strait to Timor, Aru Islands, Western New Guinea and Moluccas.
8. Java Sea Region. Southern Celebes, S.E. Borneo, North Java, Malaya and Gulf of Siam.
9. Sulu Sea Region. Annam, Northern Borneo, Northern Celebes and Philippines.
10. Japanese Region. S.E. China, Formosa and Southern Japan.
11. Dampierian Region. N.W. Australia and Western Australia north of Sharks Bay.

C. PACIFIC PROVINCE.

12. Queensland Region. New South Wales to Port Curtis Queensland, Lord Howe Island and Norfolk Island.
13. Melanesian Region. Northern and Eastern New Guinea, Bismark Archipelago, Solomon Islands, Torres Straits Islands, New Hebrides, Loyalty Islands and New Caledonia.
14. Samoan Region. Kermadec Islands, Fiji, Tonga, Niue and Samoa.
15. Oceanic Region. Gilbert and Ellis Islands, Tokelau and Marshall Islands.
16. Micronesian Region. Caroline Islands, Palau Islands, Guam, Marianas and Bonin Islands.
17. Polynesian Region. Cook Islands, Society Islands, Tuamotus, Marquesas Islands and Easter Island.
18. Hawaiian Region. Hawaiian Islands and Midway Island.

Practically every worker will disagree in detail with the Schilders' scheme which in places suggests convenience rather than the expression of natural biogeographic areas. Nevertheless the scheme provides a useful framework upon which either to build or to dismantle.

Perhaps because I know my own region best I find most fault with the East Australian-South West Pacific section of the scheme. For instance, No. 12, the "Queensland Region" has been subdivided to the satisfaction of Austro-Neozelanic workers on the basis of systematic studies in mollusca, echinoderma and algae, with a recent endorsement from the ecologists (Bennett & Pope, 1953).

There is general recognition of the Peronian warm-temperate province for New South Wales and the Solanderian tropical province for Queensland to Cape York. It may be noted, however, that Whitley (1932) restricted the Solanderian to the Great Barrier Reef and added a new province, the Banksian, for coastal Queensland. A further subdivision of Schilders' "Queensland Region", the Phillipian has been advocated for Norfolk and Lord Howe Islands by Whitley (1932).

No. 13, the "Melanesian Region", should surely include Fiji which has a similar continental fauna to that of the Solomon Islands and New Caledonia. The latter incidentally was segregated as a special province, the Montrouzierian, by Whitley (1932).

On molluscan evidence there seems to be no need to recognise more than one province to cover the Schilders' three South West Pacific "Regions", the Samoan, Oceanic and Polynesian.

I am unable to assess the value of the "Micronesian Region" but undoubtedly the "Hawaiian Region" is a good one. Although most of the widespread Indo-West Pacific coral fauna is represented in the Hawaiian group there is a relatively high percentage of endemic organisms. The "Oceanic Region" should certainly disappear since its chief characteristic is the almost total absence of endemic species.

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HAWAIIAN
Hawaiian Is
Fanning I
Christmas I
Marshall Is
Gilbert Is.
Phoenix Is
Ellice Is
POLYNESIAN
Marquesas Is
Low Archipelago
Society Is
Cook Is
Samoan Is
Austral Is.
Pitcairn I.
Easter I.
OCEANIC
MICRONESIAN
Solomon Is
Santa Cruz
New Hebrides
Fiji Is.
New Caledonia
Norfolk I
Kermadec Is
MELANESIAN
SAMOAN
QUEENSLAND
S. AUSTRALIA
DAMPIERIAN
MOLUCCAN
JAPANESE
SULU SEA
JAVA SEA
SUMATRAN
Kaimar Is
INDIAN
Andaman Is
Maldive Is
Seychelle Is
Mauritius
PERSIAN
ERYTHRAEAN
LEMURIAN
Galapagos Is.
Jamaica
Chatham Is.
Auckland I.
Campbell I.
Macquarie I
Crozet Is.
Kerguelen I.

AN OUTLINE OF THE DISTRIBUTION OF PACIFIC DEEP-SEA ANIMALS

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When it is remembered that the existence of a deep-sea fauna has been known for less than a century, that the Pacific Ocean covers 50 per cent of all seas, and that the Pacific deep-sea fauna has been studied relatively less than those of the Indian and Atlantic Oceans, it is no wonder that an outline of the distribution of the animals must rest on a very scanty material.

We shall only consider true deep-sea animals, i.e. those living at 2000 meters or deeper, the abysso-pelagic and abyssal fauna. In this way are excluded such species as may be considered to have their main distribution on the continental slopes. Again this means by far the greater part of the Pacific, 87.3 per cent, as the continental shelves cover only 5.7 per cent and the continental slopes 7.0 per cent of this ocean (Sverdrup, Fleming & Johnson 1946).

Ekman (1953a, p. 303) is of the opinion that "the open-sea abyssal can be divided zoogeographically into only three or four main regions: an Atlantic, Pacific, Arctic and perhaps Antarctic region." And on p. 291: "Not even for the most extreme abyssal species of the benthos can a cosmopolitan distribution, however, be considered as the rule. The lack of common species between the Atlantic and the other oceans may up to a point be due to the insufficient knowledge of the fauna, but this is only partly true." When the term "Pacific" is used in this connection, Ekman means "an Indo-Pan-Pacific region" (p. 292).

The echinoderms are especially well suited for consideration regarding the distribution of deep-sea animals because they are numerous qualitatively as well as quantitatively, and they are easily caught. Therefore, it is of special interest to compare the conclusions of Madsen (1953) with Ekman's statements above. Madsen is of the opinion "that the known distribution of the deep-sea Echinoderms strongly favours the view that the main zoogeographical regions of the extreme deep-sea of today are, on the one hand, the Pacific, and, on the other hand, the combined Atlantic and Indian Oceans. As the deep-sea region next in importance to these comes the Antarctic deep-sea region, but other regions of the deep-sea I think it difficult to define from the

distribution of the Echinoderms, and special fauna elements in certain regions will probably mostly prove to be off-shoots of neighbouring archibenthal regions."

To get such different opinions to meet is very difficult at a time when much new evidence is under way, e.g. from The Swedish Deep Sea Expedition 1947–48 in the North Atlantic (Nybelin 1951, 1953), from the Russian investigations in the North West Pacific (Zenkevitch 1953), and from the Danish Galathea Expedition Round the World 1950–52 (Bruun 1951, 1953a, 1953b, Dahl 1953, Gislén 1953, Kirkegaard 1953, Madsen 1953, ZoBell 1953). At present it can only be done in a sketchy way, by putting forward some postulates for further examination. It should also be emphasized that very much more collecting must be carried out even if the deep-sea expeditions after 1945 have brought knowledge a step forward.

As true abyssal animals only species which breed regularly at depths exceeding 2000 meters should be considered. Very little is known about the reproduction of abyssal animals, but it may be expected that certain species breeding on the continental slopes may have juvenile stages carried by currents to deeper water, where they can live but not breed.

A parallel example would be the abyssal records of the deep-sea eel *Synaphobranchus*; different species of this genus have been found in all oceans, from the Arctic Circle in the Atlantic to the latitudes of New Zealand in the Pacific. But the distribution is governed by the epipelagic breeding-places, which seem to be much the same as those of the freshwater eel (*Anguilla*), as shown by the distribution of the leptocephali of both genera (Bruun 1937).

Some examples of how scanty is our knowledge of the deep-sea animals may be given. The polychaete *Nepthys elamellata* Eliason was found only in 1948 in the North Atlantic at 4270 and 4600 meters by The Swedish Deep-Sea Expedition; it was found again in the Pacific in the Kermadec Deep (Kirkegaard 1955) at 6140–6960 meters.

The elasipod holothurian *Elpidia glacialis* Théel which has been considered as one of the most typical species of the Arctic Ocean, was taken by the Galathea in several localities in the Java and the Banda Deeps and in one of the hauls in a number of about 3000 specimens (Madsen 1953). From the Banda Deep at a depth of 7250 meters may also be mentioned the depth record of the irregular echinoid *Pourtalesia aurorae* Koehler caught by the Galathea, while this species was only known formerly from the Antarctic from 440–1690 meters (Madsen 1953). The same author also gives the Galathea finds of another peculiar irregular echinoid genus *Echinosigra* (which hitherto was known only from the North Atlantic and the Atlantic sector of the

Antarctic); it was found in the Indian Ocean (*E. paradoxa* Mortensen) and in the South West Pacific (*E. phiale* [Wyv. Thomson]).

Finally may be mentioned a fish *Bathymicrops regius* Koefoed, known since the Michael Sars Expedition in 1910 from the North Atlantic, caught there again by The Swedish Deep-Sea Expedition (Nybelin 1951), and found in the Indian and Pacific Oceans by the Galathea (Fig. 1).

More examples of this kind could be given, and many more will surely be added when present and future collections have been studied. At the same time the confused state of taxonomy of many deep-sea animals may be cleared up, and present apparent differences in the composition of the faunas may also be reduced in this way.

All this would lead to the postulate that the Pacific abyssal and abysso-pelagic fauna is part of the Cosmopolitan true deep-sea fauna. This is really to get back to the views held in the early days of deep-sea research. But this does not mean that differences in the composition of the animal communities from one area to another would not be found; indeed, they will occur and arise from two major ecological factors: 1. Depth (= pressure) and 2. Supply of food.

The importance of pressure has been evidenced very clearly from ZoBell's studies (1953) of the barophilic bacteria, especially from the Galathea samples from the deep trenches, right down to 10000 meters. The distribution of many abyssal animals indicates that they may also be called barophilic, e.g., *Bathymicrops* (Fig. 1) or sthenobathic; another group, like *Pourtalesia* and *Elpidia* mentioned above, seem to be eurybathic, as no morphological differences have been found within the enormous vertical range. The presence of physiological differences, however, cannot be excluded and seems quite likely.

Zenkevitch (1953) relates that Russian investigations in the Kurile-Kamtschatka Trench, trawling down to 9800 meters gave the following zonation:

I Surface zone, influenced by winter cooling, 0–200 m.
II Transition zone, warm oceanic water masses, 200–500 m.
III Deep-sea zone, 500–6000 m. ("normal ocean depths")
  1. Upper subzone, 500–2000 m.
  2. Lower subzone, 2000–6000 m.
IV Deep-sea trenches ("super oceanic depths") 6000–10000 m.

In accordance with the general impression derived from earlier investigations (for literature see Ekman 1953a) and the collections of the Galathea, keeping the abyssal zone from 2000 meters and downwards seems more natural. Vertically this zone may then tentatively be divided in three: 1. Depth range 2000–4000 meters, 2. Depth range

4000–6000 meters (example in Fig. 1), 3. Depth range 6000–10000 meters, the trench-faunas. It remains to be seen how such a division will work in detail; especially in the case of the trench faunas a certain endemism may be expected. If animals really are adapted to live at a pressure of e.g. 800–1000 atmospheres in the Philippine Trench, such species will not be able to spread to other trenches. The extent of endemism of the single trench fauna may also reflect to a certain degree the relative age of the trench.

In this connection it may be of interest to give a preliminary list of the deepest records of a number of animal groups, as found by the Galathea Expedition.

TABLE I

DEEPEST RECORDS OF A NUMBER OF ANIMAL GROUPS. RESULTS FROM THE GALATHEA EXPEDITION.

GROUP	DEPTH, M.	NUMBER OF SPECIES	TRENCH
Actinaria	10190	1	Philippines
Echiuroidea	—	1	—
Holothurioidea	—	2	—
Bivalva	—	1	—
Polychaeta	—	1	—
Amphipoda	9770	1	—
Isopoda	—	1	—
Tanaidacea	8210	3	Kermadec
Sipunculoidea	—	1	—
Crinoidea	—	1	—
Gastropoda	—	1	—
Hydrozoa	—	1	—
Asteroidea	7630	1	—
Echinoidea	7250	1	Banda
Cumacea	7130	1	Java
Neopterygii	—	1	—
Porifera	6960	2	Kermadec
Cirripedia	—	1	—
Brachyura	—	1	—
Anthipatharia	6940	1	Java
Scaphopoda	—	1	—
Ophiuroidea	6660	1	Kermadec
Ascidia	—	1	—
Scyphozoa	6620	1	—
Nematoda	—	1	—
Pycnogonida	6480	1	Banda
Alcyonaria	6140	1	Kermadec
Zoantharia	—	1	—
Ostracoda	5850	1	—
Bryozoa	—	1	—

The details will be found in the forthcoming scientific reports. There is a good general agreement with Zenkevitch's statement (1953), translated from German: "In the greatest depths the holothurians exceed 90 per cent of the bio-mass, followed by sponges, which do not reach 7000 meters. The Asteroidea do not reach 8000 meters, and between 8000 and 9000 meters disappear Octocorallia, Amphipoda and Isopoda, somewhat deeper than 9000 m. Actinia and Mollusca. In the greatest depths (9800 meters), studied by us by trawling, was only found Polychaeta, Echiuroidea, Holothuroidea, and Pogonophora."

The food supply varies very much from one place to another; its origin may as a rule be from the production of phytoplankton, in which case deep-sea areas close to regions with up-welling water will have faunas rich both as regards the number of species and the quantity present, as in the Eastern Pacific along the subtropical and tropical American coasts.

In other areas a considerable amount of terrigeneous débris brought out by rivers or from mangrove swamps is a very important addition; this has been found in inland seas like the Sulu, Celebes, and Banda Seas.

In certain areas with a very special circulation of the deep water, causing a much higher temperature as in the Sulu Sea (about 10°C), the composition of the fauna may be quite different, but this remains still to be studied.

The general conclusion about the Pacific abyssal fauna would therefore be that it is part of the Cosmopolitan deep-sea fauna and that differences in composition from one area to another would mainly be due to ecological factors, primarily depth and food supply; only the trench faunas may have developed endemisms.

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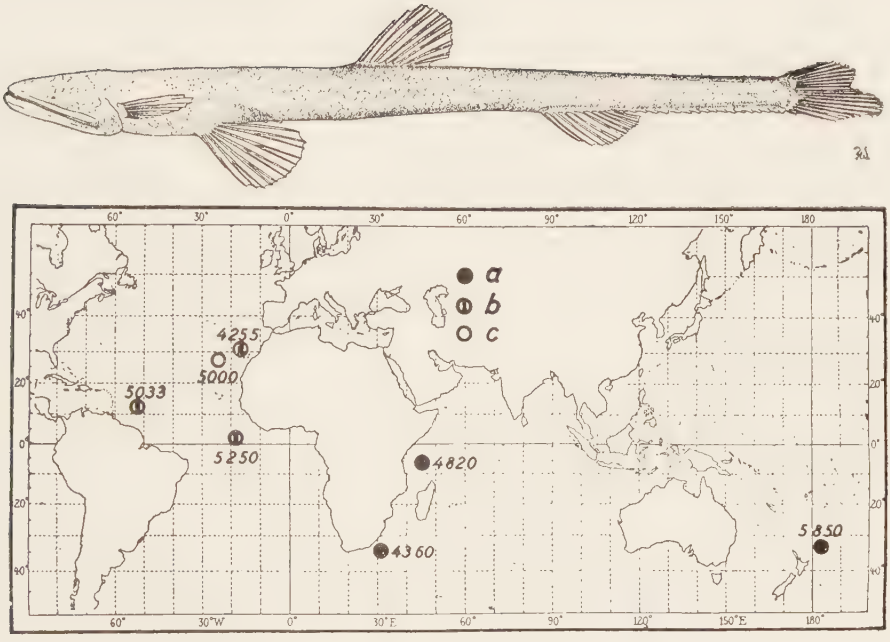

FIG. 1.—The Distribution of *Bathymictops regius* Koefoed. Caught by (a) The Galathea Expedition; (b) The Swedish Deep Sea Expedition 1947-48; (c) The Norwegian Michael Sars Expedition 1910. The figures denote the depth in meters.

DEEP-WATER BIOLOGICAL PROVINCES OF THE INDO-PACIFIC

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The bathymetric range of so-called bathypelagic fishes, based on the questionable data from the open nets in which they are normally taken, is not definitely established. In attempting to use myctophids and other "bathypelagic" fishes as indicators of biological provinces, I have come to the conclusion that most of them tend to be distributed in relation to the water temperatures of the upper 200 meters, and that they must be considered as primarily inhabitants of the superficial layers.

Abyssal bottom fishes are so rare that they do not lend themselves as satisfactory subjects for zoogeographical investigation, and some of them give hints of practically cosmopolitan distribution—a corollary of the widespread uniform habitat of the great depths.

It is therefore among the archibenthic fishes that evidence as to the limits of comparatively deep-water biological provinces must be sought. The large, widespread, almost exclusively archibenthic and comparatively well-investigated family Macrouridae provides convincing data on which it is possible to establish definite provinces in the 200 to 2000-meter layers of the Indo-Pacific, which area I propose to treat in its broad sense as including both oceans in their entirety.

The Antarctic Province is a circumglobal region of very low temperature bordering Antarctica. Its northern limits, in the intermediate depths, lie at approximately 45° south latitude, well north of the surface Antarctic Convergence. This province boasts no archibenthic macrourids, although two abyssal species, *Nematonurus armatus* and *Lionurus filicauda,* occur there, and the latter is apparently restricted to it. This province has no northern Indo-Pacific counterpart.

Immediately to the northward of the Antarctic Province lies the Antiboreal Province, some 10° to 20° in width and including the southern coasts of Australia and most of New Zealand. This province is characterized by water of moderate temperature in the intermediate depths. At least one species, *Coelarhynchus fasciatus,* extends its range throughout the entire province, being known from off the Cape of Good Hope, southern Australia, Tasmania and southern Chile. Several species—*Macruronus novae-zealandiae, Coryphaenoides denticulatus, Coe-*

larhynchus australis and *Lionurus nigromaculatus*—known only from the area of southern Australia and New Zealand, indicate the effectiveness of the wide abyssal reaches of the southern Indian and Pacific Oceans as barriers and indicate that it would be advisable to designate a distinct Tasmanian Sub-province.

The Boreal Province, characterized by moderate temperature similar to those of the Antiboreal Province, has a continuous Asiatic-American continental shelf which has provided a pathway for the wide dispersal of archibenthic species. Characteristic macrourids, the most adaptable of which have invaded the Okhotak and Bering Seas, are *Nematonurus clarki, N. pectoralis, Coryphaenoides acrolepis, C. cinereus* and *C. lepturus.* This province, characterized by extended ranges does not appear to be amenable to subdivision.

From eastern Australia and the Solomon Islands a broad tongue of warm water, centered on the Tropic of Capricorn, extends eastward to approximately 120° west longitude, and this may be designated the Australo-Pacific Province. The region is poorly explored, particularly in its eastern portion, but its few known macrourids seem to be limited to the province. Among them are *Bathygadus cottoides, Coryphaenoides rudis, Coilorhynchus kermadecus* and *Cetonurus crassiceps.* The numerous islands dotting its entire expanse provide ample archibenthic habitats and, with further investigation, it may be possible to establish several subprovinces within this area.

Extending eastward from southern Japan and the northern Philippines is a deep warm-water mass similar to but somewhat smaller than that of the Australo-Pacific Province. Lack of islands throughout the greater part of its extent restricts archibenthic habitats to its western portion. This Japanese Province shows, through half a dozen species which range far to the southward, some degree of relationship to the Indo-Australian Province (to be discussed later), but it has numerous species not found elsewhere. An incomplete list includes *Bathygadus antrodes, Gadomus multifilis, G. colletti, Nematonurus longifilis, Coryphaenoides marginatus, C. altipinnis, C. nasutus, Coelrhynchus kishinouyei, C. jordani, C. productus, C. tonkiensis, C. japonicus, Hymenocephalus lethonemus, Lionurus garmani, L. misakius* and *L. condylura.*

The major portion of the Indian Ocean, from its northern borders to almost 40° south latitude and excluding only the extreme eastern portion between Java and Australia, appears to constitute a single province characterized by warm waters at very considerable depths. Little is known of the fauna of its southeastern section, but numerous endemic species extend their ranges from southeastern Africa to the Bay of Bengal and the Andamen Sea. Among these can be counted *Cory-*

phaenoides lophotes, C. wood-masoni, Coelorhynchus flabellispinus, C. quadricristatus, Hymenocephalus cavenosus, H. heterolepsis, Ventrifossa petersoni, Lionurus polylepis, L. investigatoris, L. brevirostris, L. semiquincunciatus and *Mataeocephalus microstomus.*

Differing markedly from the Indian Ocean Province, the Indo-Australian Province, which comprises the Philippines and the East Indies, is characterized by comparatively cold water in intermediate depths. Bordered to north and south by the warm Japanese and Australo-Pacific Provinces, its cool deep temperatures are not duplicated in the western Pacific between latitudes 35° north and south. This is in strong contrast to the surface layers in which the warmest water occurs in the equatorial region. Another large group of endemic species—*Gadomus denticulatus, G. introniger, Coryphaenoides hyostomus, Coelorhynchus argentatus, C. maculatus, C. argus, C. amithi, C. radcliffi, C. platorhynchus, C. commutabilis, C. macrorhynchus, Hymenocephalus longiceps, H. nascens, Ventrifossa nigrodorsalis, V. divergens, V. nigromarginata* and *Trachonurus villosus*—ranges throughout this area.

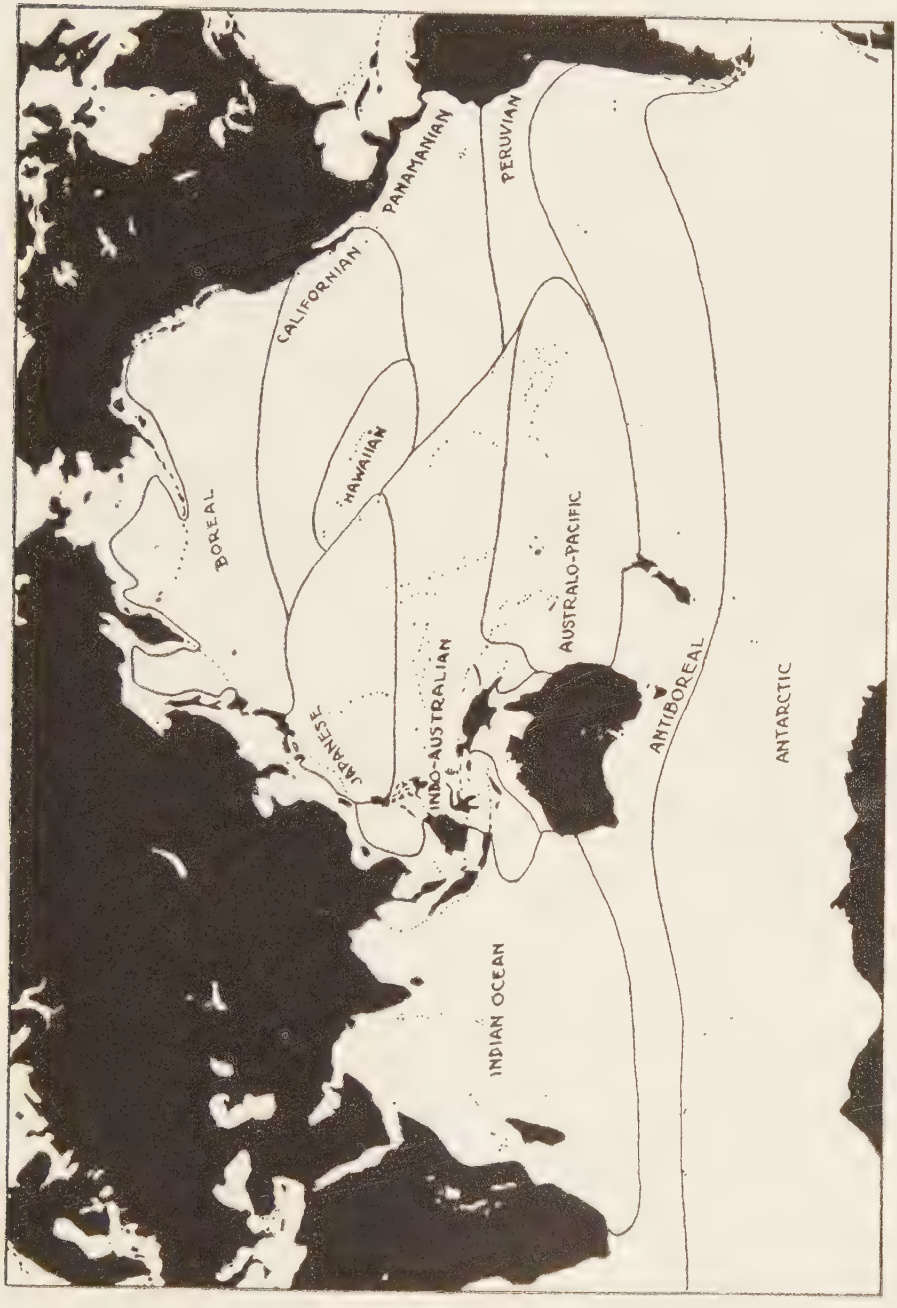
The Indo-Australian Province may readily be subdivided. The Sulu Sea, with its shallow sills and consequently very warm deep water, has given rise to a few endemic species such as *Coelorhynchus sexradiatus, C. notatus* and *C. triocellatus,* and forms the Sulu Subprovince which tends to isolate the Philippines from the East Indian region. Thus limited to the Philippine Subprovince are *Bathygadus sulcatus, Gadomus magnifilis, Coryphaenoides semiscaber, Coelorhynchus quincunciatus, C. thompsoni, C. velifer, C. macrolepis, C. acutirostris, Hymenocephalus longipes, Malacocephalus luzonensis, Ventrifossa macronemus* and *V. lucifer,* while *Bathygadus filamentosus, Coryphaenoides tydemani, C. aequatoris, Coelorhynchus acantholepis, Lionurus evides, L. vittatus, L. parviceps* and *Mataeocephalus adjustus* are known only from the East Indian Subprovince.

In addition to the very large number of endemic species in the Indo-Australian Province, several more eurythermic forms such as *Bathygadus spongioceps, B. furvescens, Macrouroides inflaticeps, Malacocephalus laevis* and *Lionurus pumiliceps* range widely throughout both this area and the Indian Ocean; others such as *Gadomus multifilis, Coelorhynchus parallelus, Cetonurus robustus, Hymenocephalus striatissimus* and *Trachonurus villosus,* range from the East Indies to southern Japan, while two of them extend far into the Indian Ocean, and one of these is found in northern New Zealand as well. The combined ranges of all of these forms centering in the Indo-Australian Province indicate that this area together with the Indian Ocean, the Japanese and the Australo-Pacific Provinces constitute a single great unit which may be termed the Indo-Pacific Superprovince.

Due to inadequate exploration the eastern limits of the Indo-Australian Province are unknown. It may, however, be stated that, although its deep waters have hydrographic characteristics very similar to those of the Hawaiian Islands, the wide intervening abyssal area has acted as an effective dispersal barrier with a consequent attenuation of the fauna and a great endemism in the Hawaiian Province. None of the Hawaiian macrourids are known from other areas. Among the endemic forms may be listed *Bathygadus bowersi, Coelorhynchus gladius, C. atratrum, C. doryssus, Hymenocephalus antraeus, H. aterrimus, H. striatulus, Malacocephalus hawaiinesis, Lionurus antherodon, L. ctenomelas, L. propinquus, L. holocentrus, L. gibber, Mataeocephalus acipenseriuus* and *Trachonurus sentipellis.*

The Panamanian Province, comprising the west coast of Central America and northern South America, is even more isolated from the East Indies than is Hawaii, and its deep waters are warmer than those farther west. Here appears another large group of endemic forms: *Trachyrhynchus helolepis, Coryphaenoides bucephalus, C. capito, C. boops, C. carminifer, C. anguliceps, Coelorhynchus canus, Lionurus loricatus, L. convergens, L. latirostris* and *L. fragilis.*

The gap on the North American coast between the Boreal and Panamanian Provinces suggests the existence of still another faunal area. This Californian Province is poorly defined. Of its three known archibenthic macrourids, *Lionurus liolepis* is endemic, *L. stelgidolepis* ranges to Panama and is undoubtedly a southern derivative, while *Coryphaenoides acrolepis* is a boreal species which extends to Kamchatka. It is probable that a comparable Peruvian Province exists in the southern hemisphere, but our knowledge of the deep-water fishes of that area is so incomplete that no definite conclusions can be reached.


BOREAL
CALIFORNIAN
HAWAIIAN
PANAMANIAN
PERUVIAN
JAPANESE
INDO-AUSTRALIAN
AUSTRALO-PACIFIC
ANTIBOREAL
ANTARCTIC
INDIAN OCEAN

SOME OUTLINES OF PLANKTON CONCENTRATION IN THE EASTERN AND TROPICAL PACIFIC *

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Introduction

In recent years, especially following World War II, there has been a marked increase in research involving marine plankton along part of the west coast of North America and in parts of the tropical Pacific. While much of this work was undertaken to elucidate fisheries problems, the results will doubtless prove of much wider application in general marine biology and oceanography.

From these studies there is emerging in broad outlines a picture of relative plankton concentrations and of pelagic communities that characterize different areas, water masses, or current systems. It is reasonable to believe that the relative concentration of plankton (a fundamental source of food) will be reflected in the type and distribution of the benthic communities.

Figures 1 and 2 for the eastern Pacific are from one of several cruises made jointly by Scripps Institution of Oceanography, the U.S. Fish and Wildlife Service, the California Fish and Game and the California Academy of Sciences—all in connection with the California Cooperative Sardine Research Program. (Progress Report 1950 and 1952.)

Figures 3–6 for the tropical Pacific are based on collections made during Scripps Institution's "Capricorn Expedition" 1952–53.

West Coast, North America

The area of routine study varies somewhat with season but in total it extends over a thousand miles along the coast of California and Baja California and seaward up to 350 miles. Three oceangoing vessels participated in each monthly cruise.

Methods. The tow nets employed were approximately 5 meters in length with a mouth opening of one meter in diameter, and constructed of No. 30xxx grit gauze (mesh opening 0.65 mm). A flow meter provided a measure of the water strained.

* Contribution from the Scripps Institution of Oceanography (new series), Number 658.

In operation the nets were drawn obliquely through the water mainly from a depth of 70 or 150 meters to the surface.

Results. There is usually a large northern area of high plankton production within the California Current (Fig. 1) and along the coast as indicated by total zooplankton volume (displacement volume after removal of large forms) per thousand cubic meters of water strained by the 1-meter net.

In Figure 2 is shown the volume distribution for cruise No. 3 which provided a good geographic coverage with rather typical results. In Figure 2 the average for 70-Om hauls for the whole area was 208cc/1000m^3 of water, but for 64 northern stations the average was 300cc/1000m^3 as contrasted with an average of 75cc/1000m^3 for 43 southern stations. The larger northern volumes consisted mainly of the northern copepods *Calanus cristatus, C. tonsus* and *Eucalanus bungii* of both northern and southern varieties.

There is also usually a marked decrease in volume at the offshore stations, particularly in the southern section. For example, in Figure 2, the outer 2 to 5 stations of the seven southern lines yielded an average of 23.6cc/1000m^3 for 26 stations. Commonly there is an increase in volumes along the coast in the vicinity of central Baja California.

For three successive years, April and May have yielded volumes somewhat above the average for the year. October and November are somewhat below average. The other months sampled were less consistent though June and July catches may be relatively high and September and December low.

Contributing to the enrichment of the plankton are certain areas of upwelling along the coast where the water is characterized by lowered temperatures and oxygen content and increased salinity and phosphate content. This upwelling is associated with periods of northwest winds, usually occurring during spring and summer. The coastal areas most affected from north to south are Cape Mendocino, Soberanes Point, Point Conception and the region off central Baja California.

The coastal area is devisable also on a qualitative basis which outlines more or less clearly adjoining northern and southern pelagic faunal areas. These are separated roughly by the 13°–14°C isotherms for the 50-meter depth. In spring the isotherms cut obliquely from offshore at 35–40′ North latitude towards the coast of Baja California at 30°N (Fig. 2).

Conspicuous in the plankton of the northern area are especially the copepods *Calanus cristatus, C. tonsus,* and *Eucalanus bungii. Candacia columbiae, Epilabidocera amphitrites,* while rare, are indicative of the northern fauna. Other planktonic crustacean groups with species

that characterize the areas (with some overlapping of sparse numbers) are the hyperiid amphipods (T. Bowman M.S.) and the euphausiids (B. Boden, M.W. Johnson and E. Brinton, M.S.).

South of 35°N the southern extension of the more abundant northern species is commonly 150 miles offshore in the California current in the deeper layers. Apparently they do not readily survive the northward flowing counter currents and eastern portions of eddies that often prevail inshore south of Point Conception.

In the offshore area the picture is not so clear since the distribution there involves more oceanic and warm water species which extend into the warm surface waters to the north outside the California current, and in the south, tend to impinge more closely upon the coast of Baja California.

The plankton volumes obtained by the Scripps Institution "Shellback Expedition" 1952 have been studied by Milner B. Schaefer and Leo Berner, who find an offshore continuation of low plankton all the way to the equatorial current system.

Tropical Pacific

It has long been known that in certain offshore oceanic areas in the region of the equatorial current system, there occurs an increased abundance of fish, birds and larger invertebrates. More recent studies have shown that there is also an increase in the plankton abundance, thus providing an explanation for the impressive display of higher forms. The equatorial crossings reporting increased plankton within the current system are Graham (1941) for the Carnegie crossing at approximately 140°W; King and Demond (M.S.) for Pacific Oceanic Fisheries Investigations crossings in the central Pacific between longitudes 155° and 175°W. King and Demond report similar findings by Takashi Tokioka (1942) along 134°E.

In the present paper is given the results of plankton hauls taken aboard the Scripps Institution vessel "Horizon" in connection with the "Capricorn Expedition" in 1952–53. The area covered extends over much of the tropical Pacific mainly below the equator but with crossings of the equatorial current system at about 169°E and about 124°W. (Figs. 3 & 4)

Methods: Two types of nets were employed: (1) a 1-meter net, of the type described above, for the general larger zooplankton, and (2) a small truncated net of No. 20 bolting silk to sample the microplankton. This second net had a filtering cone one meter long attached to a ring 28 cm. in diameter. The truncated portion had a mouth opening of 18 cm.

In operation the 1-meter net was hauled obliquely from about 150 meters to the surface with 200 meters of wire out. It was retrieved at a rate of 10 m. per minute, giving a 20–minute haul. The towing angle was maintained as nearly as possible to 45°. A few deeper hauls were made with 600 m. of wire out. In these hauls the retrieving time was 20m/min.

The amount of water filtered was calculated on the basis of performance of identical nets provided with flow meters and towed under similar conditions.

The relatively small volumes obtained in the deep hauls with 600 m. wire out (Fig. 3) would indicate that the major concentration of zooplankton is in the upper layers, for while the net strained much more water during the deep hauls, the time spent in the upper presumably more concentrated layer was one-half that spent there during the shallow hauls.

The No. 20 net was lowered and raised vertically by hand, sampling from 50 meters to the surface.

Results: The volume of zooplankton caught by the 1-meter net was measured by displacement in cc. and is graphically shown for each station in Figure 3.

The noteworthy feature is the marked increase in plankton at both crossings of the equatorial current system especially at the eastern crossing where a greater number of samples were taken. The volumes of the 1-meter net hauls in the current system are made up primarily of copepods, but chaetognaths were also abundant. Euphausiids and siphonophores, while common, did not add materially to the bulk.

The volumes of microplankton are similar in geographic distribution to those obtained by the 1-meter net (Fig. 4). In each haul there is a mixture of phyto and zooplankton, but at the eastern crossing the phytoplankton constituted about 3/4 of the settling volumes. The pictures presented in Figures 3 to 6 are not materially influenced by diurnal migration of the plankton for most of the samples were taken during daylight hours. In Table I, the beginning time of sampling is shown for the 1-meter net hauls.

In the eastern crossing of the equatorial current system only one station (at 01°05′S) was sampled during darkness with the No. 20 net.

In Figure 5 is shown the thermal structure of the water at the western crossing of the equator together with the corresponding microplankton volumes at eleven stations along the section. There is a moderately high even plankton concentration from about 02°S to 03°N, between which at about 01°–02°N there is some indication of upwelling.

TABLE I

BEGINNING TIME OF SAMPLING AT STATIONS SHOWN IN FIGURE 3

STATION	TIME	STATION	TIME	STATION	TIME
1	11:11	13	07:30	25	17:05
2	10:45	14	21:44	26	08:35
3	15:25	15	14:50	27	21:10
4	11:20	16	06:58	28	09:06
5	11:40	17	06:46	29	08:40
6	09:40	18	09:46	30	17:31
7	13:23	19	18:23	31	16:54
8	06:41	20	16:57	32	08:12
9	20:30	21	13:27	33	16:54
10	15:37	22	21:16	34	17:44
11	07:51	23	11:27	35	08:21
12	07:06	24	08:51		

In Figure 6 the plankton volumes from both types of net hauls are shown in relation to the isotherms at the eastern crossing. In the absence of complete hydrographic data and somewhat too great spacing of the stations, it is not possible to say with certainty just what portion of the current system supports the greatest plankton volumes, but the structure of the water mass and the volumes obtained suggests a high plankton concentration at the southern edge of the counter current.

In contrast to the plankton-rich waters of the equatorial currents, there was a dearth of plankton along much of the ship's course north and northwest of the Fiji Islands and from these islands westward below the equator through the Tonga, Samoa, Society and Marquesas Island groups. The "Dana" also found low plankton volumes in much of this area (Jaspersen 1935).

Increased plankton volumes were again obtained in the eastern South Pacific over the Easter Island Rise between about 10° to 16° S, 113° to 124° W (Figs. 3-4). Correlated with this more abundant plankton, there was a marked increase in the number of schools of flying fish and of squids.

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ILLUSTRATIONS

FIGURE 1

Hydrographic conditions off the coast of California, Oregon and Baja California. Cruise 3 April 28-May 14, 1949.

FIGURE 2

Plankton volumes off the coast of California, Oregon and Baja California. Cruise 3 April 28-May 14, 1949.

FIGURE 3

Plankton volumes for 1-meter net hauls along the course of the "Capricorn Expedition". Black columns for hauls with 200 m. wire out, open columns with 600 m. wire out.

FIGURE 4

Microplankton volumes with No. 20 mesh net.

FIGURE 5

Microplankton volumes together with isotherms at a series of stations across the western crossing of the equatorial current system.

FIGURE 6

Plankton volumes together with isotherms at the eastern crossing of the equatorial current system. Open columns for 1-meter net hauls, block columns for microplankton hauls—not drawn to same scale (see Figs. 3 & 4 for vol. readings).

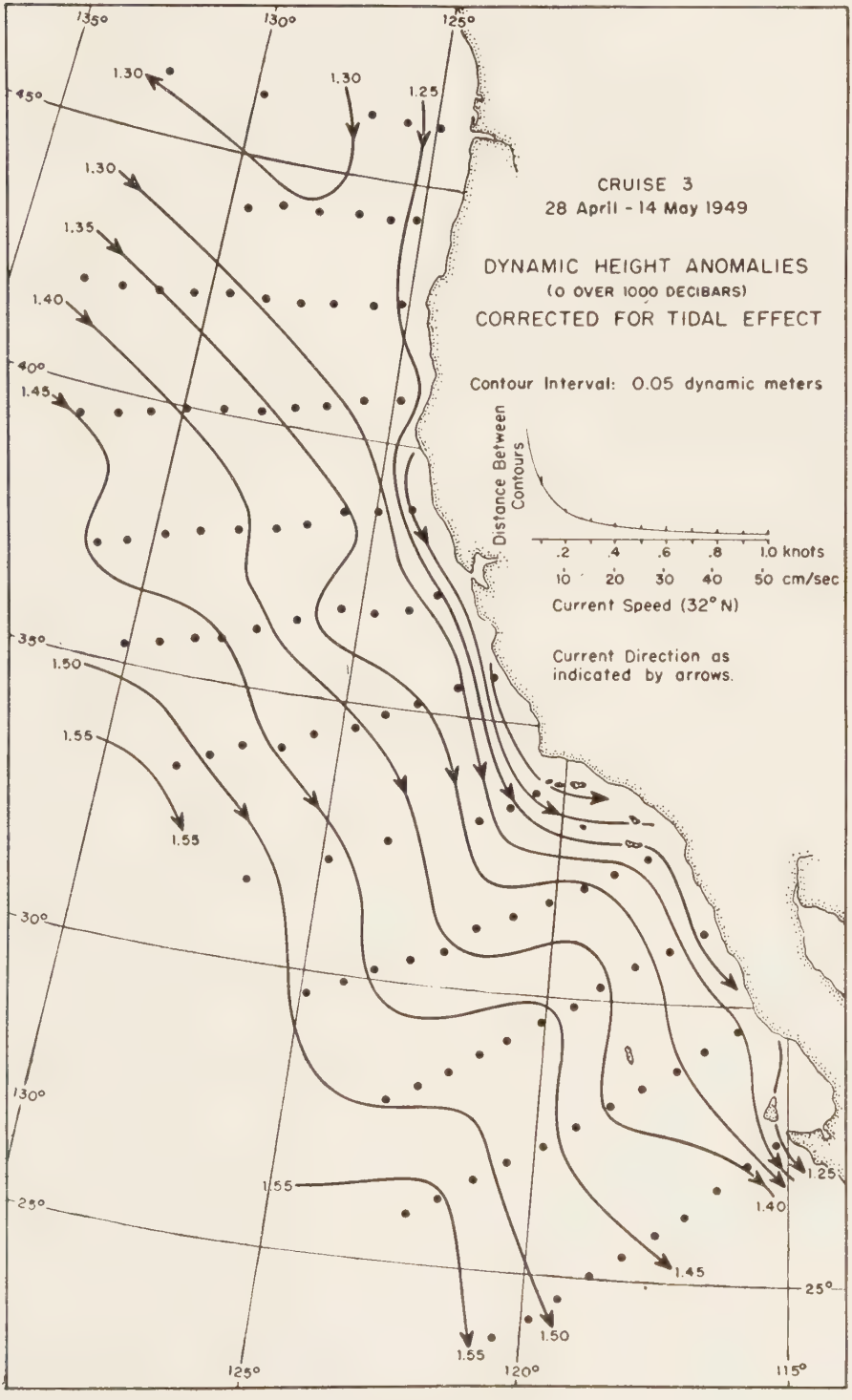

135°
130°
125°
45°
40°
35°
30°
25°
120°
115°
1.30
1.30
1.25
1.30
1.35
1.40
1.45
1.50
1.55
1.55
1.55
1.55
1.50
1.45
1.40
1.25
CRUISE 3
28 April - 14 May 1949
DYNAMIC HEIGHT ANOMALIES
(0 OVER 1000 DECIBARS)
CORRECTED FOR TIDAL EFFECT
Contour Interval: 0.05 dynamic meters
Distance Between Contours
.2 .4 .6 .8 1.0 knots
10 20 30 40 50 cm/sec
Current Speed (32° N)
Current Direction as indicated by arrows.

FIGURE 1

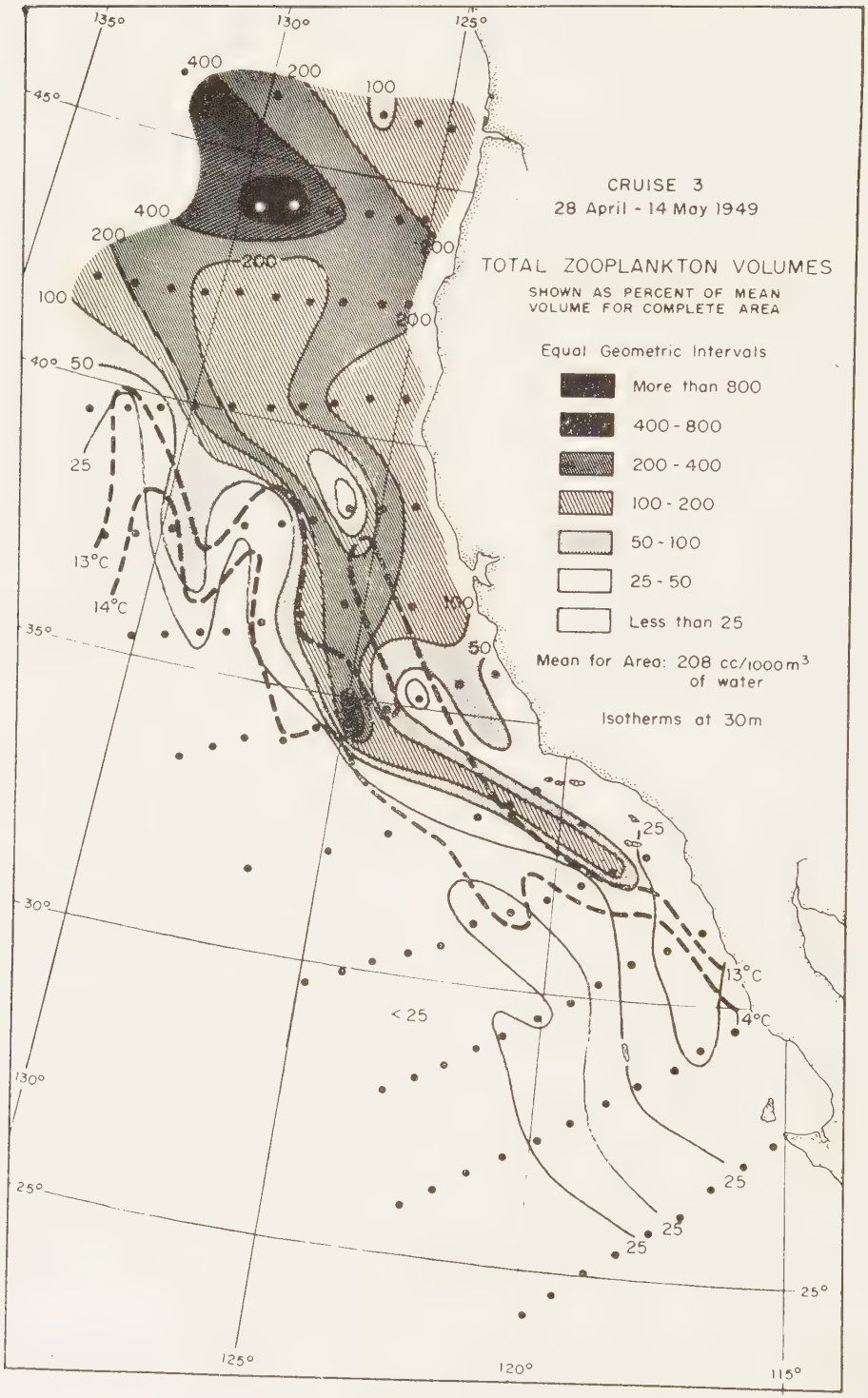
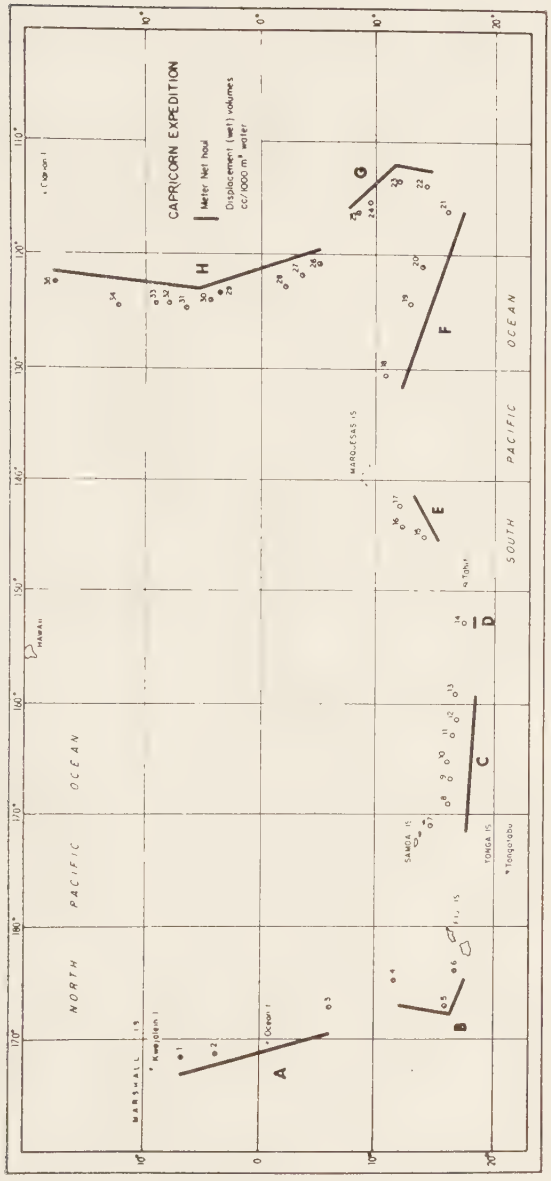

CRUISE 3
28 April - 14 May 1949
TOTAL ZOOPLANKTON VOLUMES
SHOWN AS PERCENT OF MEAN VOLUME FOR COMPLETE AREA
Equal Geometric Intervals
More than 800
400 - 800
200 - 400
100 - 200
50 - 100
25 - 50
Less than 25
Mean for Area: 208 cc/1000m³ of water
Isotherms at 30m
135°
130°
125°
120°
115°
45°
40°
35°
30°
25°
400
200
100
50
25
13°C
14°C
< 25

FIGURE 2


CAPRICORN EXPEDITION
Meter Net haul
Displacement (wet) volumes
cc/1000 m³ water
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
MARSHALL IS.
HAWAII
SAMOA IS.
TONGA IS.
MARQUESAS IS.
TAHITI
Kwajalein I.
Ocean I.
Canton I.
Tongatabu
A
B
C
D
E
F
G
H

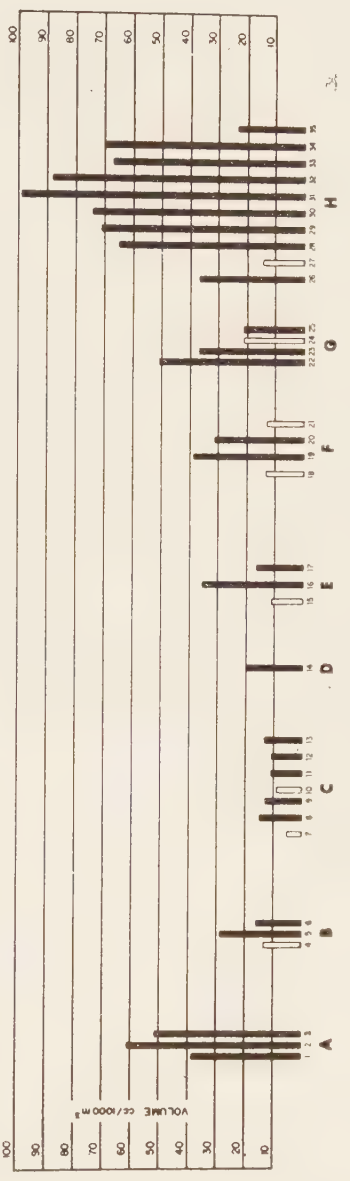

VOLUME cc/1000 m³
A
B
C
D
E
F
G
H

FIGURE 3

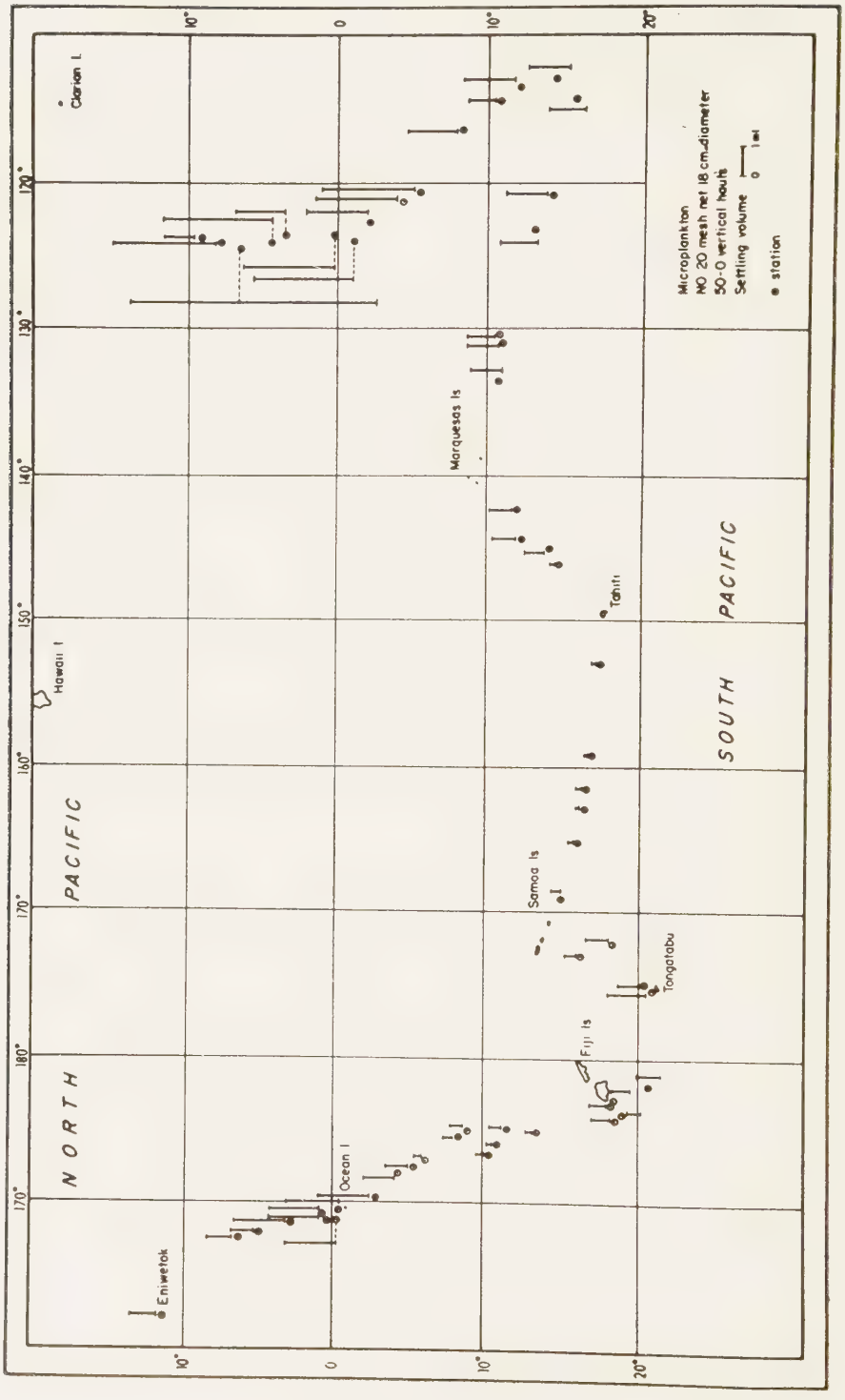

NORTH
PACIFIC
SOUTH
PACIFIC
Eniwetok
Ocean I
Hawaii I
Clarion I
Fiji Is
Tongatabu
Samoa Is
Marquesas Is
Tahiti
170°
180°
160°
150°
140°
130°
120°
10°
0
10°
20°
Microplankton
NO 20 mesh net 18 cm. diameter
50-0 vertical hauls
Settling volume 0 1 ml
station

FIGURE 4

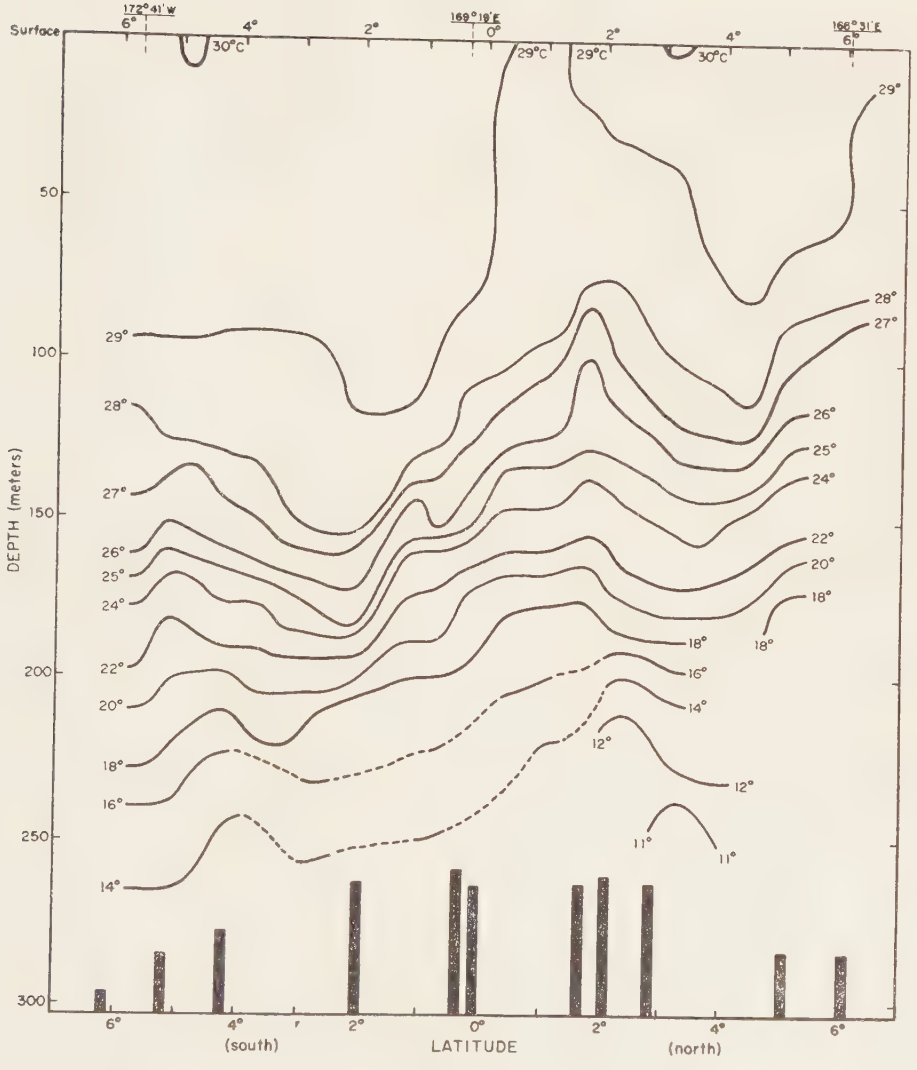

172°41' W
169°19' E
166°31' E
Surface
30°C
29°C
29°C
30°C
29°
28°
27°
26°
25°
24°
22°
20°
18°
16°
14°
12°
11°
DEPTH (meters)
50
100
150
200
250
300
6°
4°
2°
0°
2°
4°
6°
(south)
LATITUDE
(north)

FIGURE 5

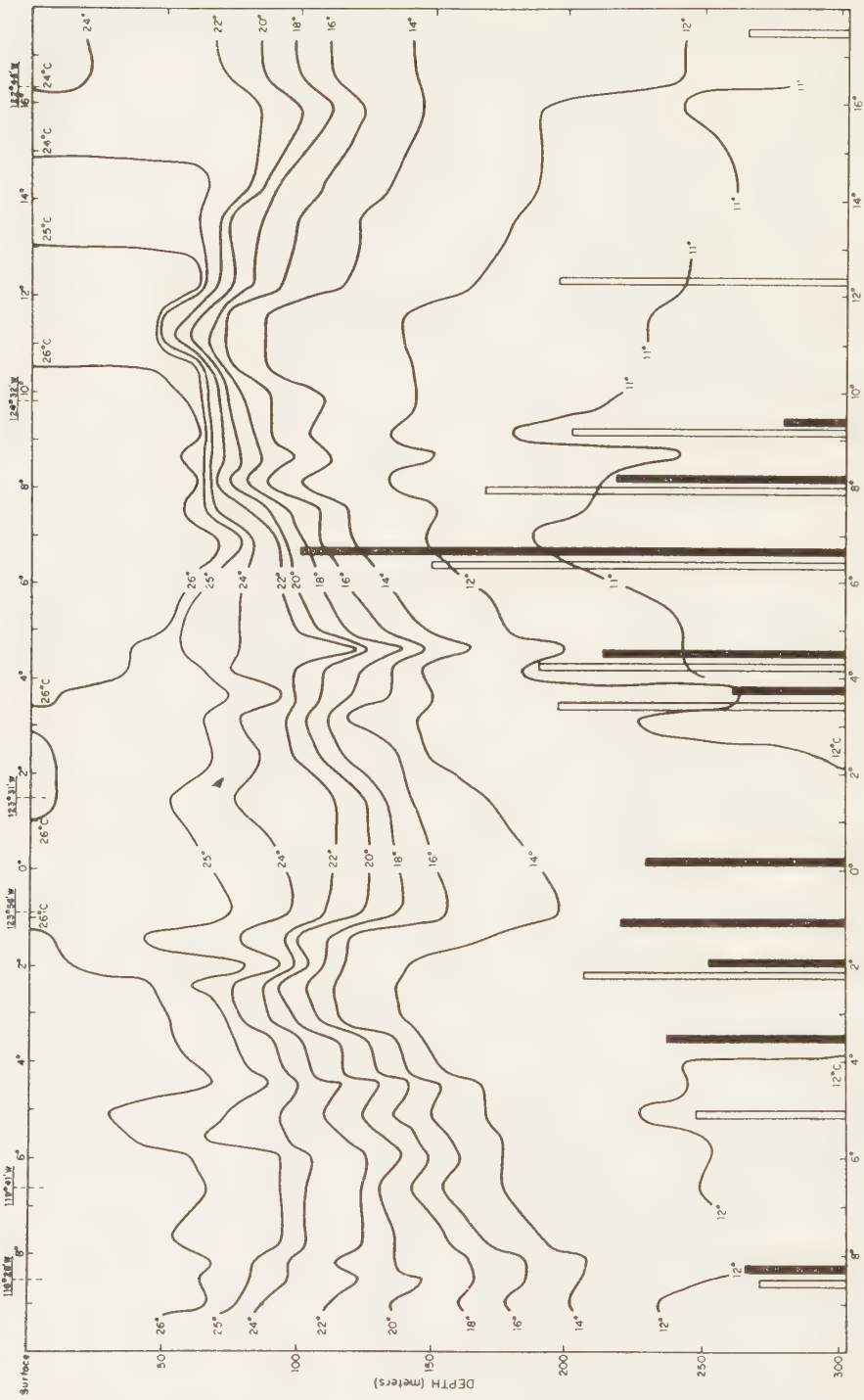

DEPTH (meters)
LATITUDE
(south)
(north)
Surface
50
100
150
200
250
300

FIGURE 6

DISTRIBUTIONAL PROVINCES OF MARINE BRYOZOA IN THE INDO-PACIFIC REGION [1,2]

By Yaichiro Okada [3]
and
Shizuo Mawatari [4]

Although the present condition of our knowledge on the bryozoan fauna of the Indo-Pacific Region is not yet quite satisfactory, the accumulated works of numerous authors have revealed much of the truth on the distribution of the group. The following authors contributed much in the faunal study of each region: Waters (1909, 1910, 1913) and Thornely (1905, 1907, 1912, 1916) on the Bryozoa of the Indian Ocean; MacGillivray (1880–1891), Kirkpatrick (1888, 1890, 1921–1929), Waters (1887, 1889) and Hastings (1932) on that of Australia; Harmer (1915, 1926, 1934) on the Siboga collection from the East Indies; Canu and Bassler (1929) on the Albatross collection in the Philippine region; Ortmann (1889), Okada (1917, 1918, 1921, 1923, 1929) and Silen (1941, 1943) on Japanese Bryozoa; Canu and Bassler (1927) on the Hawaiian forms; Smitt (1872), Robertson (1900, 1905, 1908, 1910), O'Donoghue (1923, 1925, 1926), Hastings (1930) and Osburn (1950, 1952) on the Bryozoa of the Pacific coast of America.

In the course of our systematic study on the Cheilostomatous Bryozoa, on one hand, a large number of species were newly found distributing in the Japanese waters, and we were rather surprised to find how numerous were the species common to the Malayan region. The present paper is the preliminary report on the distribution of the Indo-Pacific Bryozoa.

Geographical Isolation

According to the recent progress of studies on the evolution, the differentiation of species is said to be accelerated by the geographical isolation in geological age. The proposition of the distributional provinces are, therefore, to be based at first on the palaeogeography of the Indo-Pacific Region. The Cheilostomata, that composing the largest part of the recent marine Bryozoa, appeared in the Jurassic, and expanded into so many species in the Upper Cretaceous time. As the

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[2] Contributions from the Research Institute for Natural Resources. No. 623.
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[4] Of the research staff of the Research Institute for Natural Resources, Tokyo, Japan.

fossil forms of the Tertiary Period show striking resemblances to the recent species, the palaeogeography of the Region will be effectually traced back to the Tertiary or the Cretaceous Period. Text-figures present the geological history of the Indo-Pacific Region.

In the Upper Cretaceous and the Eocene, the northern Pacific Ocean was isolated from both the Indian Ocean and the Antarctic Sea, and conspicuously narrowed. The southern half of the Pacific was made afterwards by the secondary fusion of the northern half and the Antarctic. During the Eocene, Oligocene and Miocene epochs, the Indian Ocean was connected with the Mediterranean Sea by one or two ways. The Ethiopian Sea was recognized connecting the Mediterranean and the Indian Ocean along the African coast.

In the Upper Eocene, the Pacific Ocean found the way to the Indian Ocean by a newly opened passage at the Malayan coast. The north Australian coast was formed nearly at the same epoch. The above-mentioned history of the Indo-Pacific Region suggests to us the possibility of the following areas significant to the specific differentiation: 1) The northern Pacific. 2) The southern Pacific. 3) The eastern coast of Africa. 4) The northern part of the Indian Ocean.

Oceanographical and Ecological Factors

Larvae: So far as we are aware, one of the most characteristic features of the Bryozoan colonies is their sessile habit of growth. The distribution of the individual colony is, therefore, accomplished only by the dispersion of minute larvae within their short swimming period of a day or two. The colony attaches to various sorts of substrata such as rocks, stones, sand grains, sea-weeds, sponges, hydrozoon stems, sea-urchins, worm tubes, brachiopod shells, bivalves, gastropod shells, other bryozoans, lobsters, crabs, and ascidians. The secondary dispersion is affected by gastropods or lobsters carrying bryozoans on them. The migration along the coast-lines proceeds thus.

The Cyphonautes, a specialized form of bryozoan larvae, is able to continue their swimming life of several weeks, thus extending their range with much ease.

Ocean Current: In addition to migration along the coast-lines, there has been a more irregular and sporadic diffusion by the agency of currents, floating sea-weeds, drifting woods and by means of ships. Wide distributional range of some species which produce Cyphonautes larvae or take their residence on sea-weeds, might be caused by the action of currents.

As is well known the Pacific Ocean is divided into two, the northern and the southern half, from the oceanographical standpoint. The North

Equatorial Current, together with the Kuro Siwo and the California Current, forms the large circulation in the northern half. The South Equatorial Current, derived from the Peruvian Current of the South American coast, goes westwards to the Papuan coast embracing numerous islands of Polynesia on its way. The Indian Ocean is also divided into two parts. The South Equatorial Current, going westwards, reaches the east coast of Africa and bifurcates toward north and south, the southern branch descending along the South African coast. The South-Western Monsoon Drift, the extended part of the northern branch, goes eastwards in July and westwards in January. The Malayan Current is derived partly from the North Equatorial Current of the Pacific and partly from the Monsoon Drift of the Indian Ocean, and runs along the Chinese coast up to Japan.

These facts suggest the probability of the following subdivision of the Region: 1) Pacific coast of America and Hawaii, 2) Polynesia and Australia, 3) Indian coast of Africa, 4) Arabian Sea and Bengal Bay, 5) Malay Archipelago and Japan.

Navigation: The important role of the navigation and the transplantation of organisms in the distribution of sessile Bryozoa may be easily recognized. The cosmopolitan distribution of *Bugula neritina, Tricellaria occidentalis, Hippothoa hyalina, Watersipora cucullata* are adequately explained by their occurrence in fouling organisms. Many of the species exhibit great adaptability to different climatic conditions, and if transported to distant regions might readily accommodate themselves to their new environment.

Water temperature: One of the limiting factors to the physiological functions of Bryozoa is the water temperature. The isothermal of 22°C crossing the middle part of Japan fairly agrees to the northern limit of the Malayan element of Bryozoa. According to our experimental study of *Watersipora cucullata,* the occurrence and settlement of larvae are most active at 18–25°C, and the activity of adult suddenly falls at a temperature lower than 12°C or higher than 28°C.

Provinces of the Indo-Pacific Region

Taking into consideration the above-mentioned factors that produce predominant influences on the distribution and after making comparisons among the bryozoan fauna of various parts of the Region, we propose here the following subdivisions of the Indo-Pacific Region on the geological, oceanographical and ecological basis:

A. Indian Subregion.

1. Ethiopian Province. (East Coast of Africa, Madagascar, Red Sea, Gulf of Aden, Gulf of Persia)

2. Indian Province. (Coast of India and Burma, Timor Sea)

B. Western Pacific Subregion.

3. Malayan Province. (Malay Archipelago, South China Sea, Philippine Islands)
4. Chinese Province. (East China Sea, Yellow Sea, Southern Japan)
5. Papuan Province. (Southern New Guinea, tropical Australia, Coral Sea)

C. Central and Eastern Pacific Subregion.

6. Hawaiian Province. (Hawaii)
7. Polynesian Province. (Polynesia)
8. Mexican Province. (Southern California, Mexico, Panama, Peru)

Constitution and Interrelationship of Bryozoa Fauna of Each Subdivision

Table I is a sum total of the known genera and species of subdivisions of the Indo-Pacific Region, revised and enlarged by our recent investigations. The upper line of each area indicates the total number of genera (in Gothic type) and species (in ordinary Roman type), and the lower line the number of genera and species that have not been found elsewhere. The number of species known only from one province seems to be rather great, but from the present condition of our knowledge, it is not easy to say which of them are really endemic.

Relation between Ethiopian and Indian Provinces: As shown in Table II the number of common species of these provinces is smaller than that of uncommon ones. The Bryozoa of the Ethiopian Province is rather closely related to that of the Atlantic, and, on the other hand, the bryozoan fauna of the Indian Province somewhat resembles that of the Malayan Province.

Relation between Malayan and Chinese Provinces: The number of genera and species in common between the two provinces is considerably great, as is clearly seen in Table III, and the boundary line can not be drawn anywhere. But it seems to be adequate to separate the Chinese Province from the Malayan Province, for the specific differences in the same genus are rather great.

The Pacific coast of middle Japan seems to be the meeting-place of northern and southern types. Arctic forms descend to it and in most cases go no further south; the tropical forms make their way up to it, and generally have not become naturalized in the colder waters beyond it.

Relation between Malayan and Papuan Provinces: Table IV indicates the common and uncommon species between these two provinces.

The relationship between the Malayan and Papuan Provinces seems to be less intimate than that of the Malayan and Chinese Provinces.

Interrelationship of the provinces of Central and Eastern Pacific Subregion: As Hawaiian and Polynesian faunas have not been thoroughly investigated, it is not easy at present to clear the true nature of their relation to that of the Mexican Province. Excluding a large number of endemic species, a fairly large part of the Hawaiian Bryozoa occurs in Japan or in California. The Polynesian bryozoans present an intimate relation with Papuan forms, but a number of them have not been found elsewhere. The Bryozoa of the Pacific coast of tropical America have recently been thoroughly investigated by Osburn, and Atlantic and Mediterranean elements observed in an eminent degree, and the occurrence of a large number of specialized forms seems to prove the propriety of the separation of this province.

The details of the distribution of genera and species are to be reported in our forthcoming paper.

TABLE I

Number of Known Genera and Species

Subregion	Indian				Western Pacific						Central Eastern Pacific					
Province	Ethiopia		India		Malay		China		Papua		Hawaii		Polynesia		Mexico	
Entoprocta	1	2	1	1	6	20	5	11	4	5	0	0	0	0	5	12
	0	0	0	0	1	13	1	6	0	0	0	0	0	0	0	1
Cyclostomata	10	21	9	21	25	111	21	104	16	45	9	10	6	17	21	86
	0	0	0	0	2	38	0	29	0	8	0	0	0	2	0	21
Ctenostomata	9	22	9	18	14	31	10	37	7	18	1	2	2	4	13	39
	0	0	0	1	0	3	0	8	0	4	0	0	0	0	0	8
Cheilostomata Anasca	18	28	25	51	98	245	65	192	46	134	14	21	16	28	97	221
	0	0	0	0	2	85	0	51	0	31	0	4	0	2	2	65
Cheilostomata Ascophora	19	29	16	44	89	230	61	299	57	179	22	47	19	40	113	263
	0	0	0	2	0	87	0	78	0	62	0	6	0	5	2	128
Total	57	102	60	135	232	637	161	643	120	381	46	80	43	89	249	520
	0	0	0	3	4	226	1	172	0	105	0	10	0	9	4	223

TABLE II

NUMBER OF COMMON AND UNCOMMON SPECIES BETWEEN ETHIOPIAN AND INDIAN PROVINCES

	COMMON		UNCOMMON	
	GENERA	SPECIES	GENERA	SPECIES
Entoprocta	1	1	0	1
Cyclostomata	6	8	7	26
Ctenostomata	6	7	6	26
Cheilostomata Anasca	16	22	11	35
Cheilostomata Ascophora	11	17	13	39
Total	40	55	37	127

TABLE III

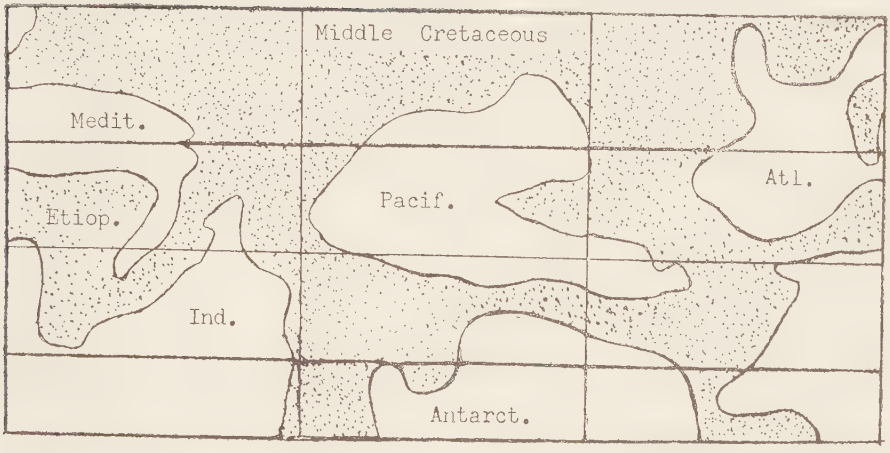
NUMBER OF COMMON AND UNCOMMON SPECIES BETWEEN MALAYAN AND CHINESE PROVINCES

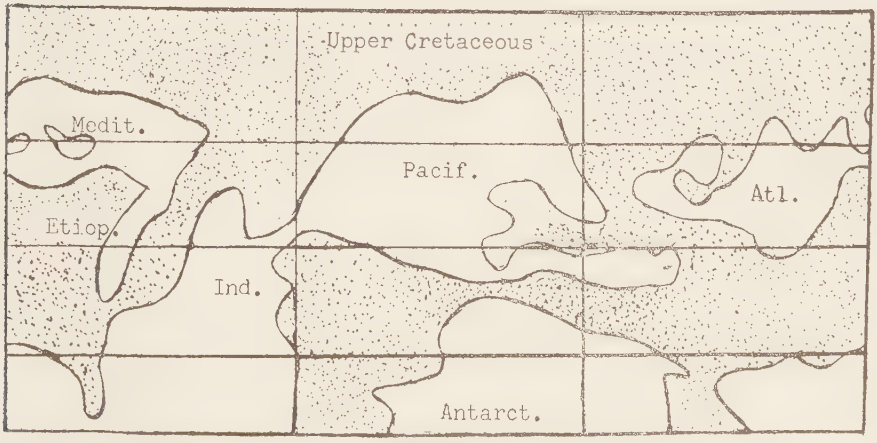
	COMMON		UNCOMMON	
	GENERA	SPECIES	GENERA	SPECIES
Entoprocta	5	5	1	21
Cyclostomata	18	59	10	96
Ctenostomata	10	21	4	26
Cheilostomata Anasca	56	123	51	191
Cheilostomata Ascophora	60	126	90	277
Total	149	334	156	601

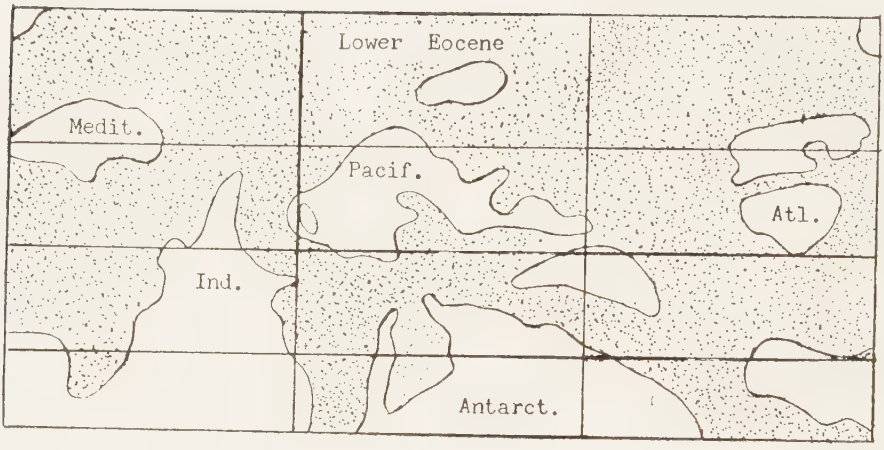
TABLE IV

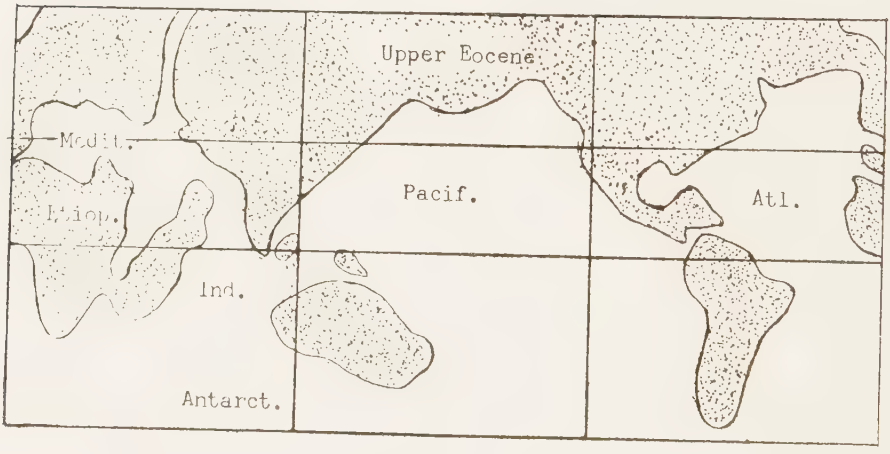
NUMBER OF COMMON AND UNCOMMON SPECIES BETWEEN MALAYAN AND PAPUAN PROVINCES

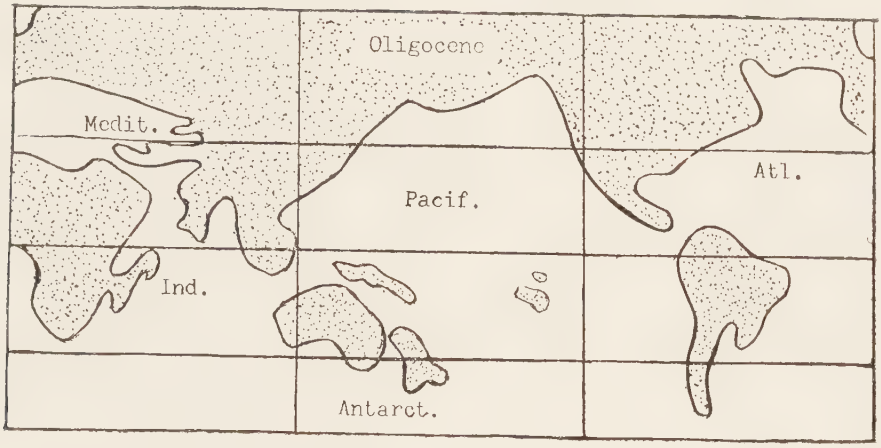
	COMMON		UNCOMMON	
	GENERA	SPECIES	GENERA	SPECIES
Entoprocta	3	3	4	19
Cyclostomata	12	30	17	96
Ctenostomata	5	9	7	31
Cheilostomata Anasca	38	67	68	245
Cheilostomata Ascophora	39	81	64	247
Total	97	190	152	638

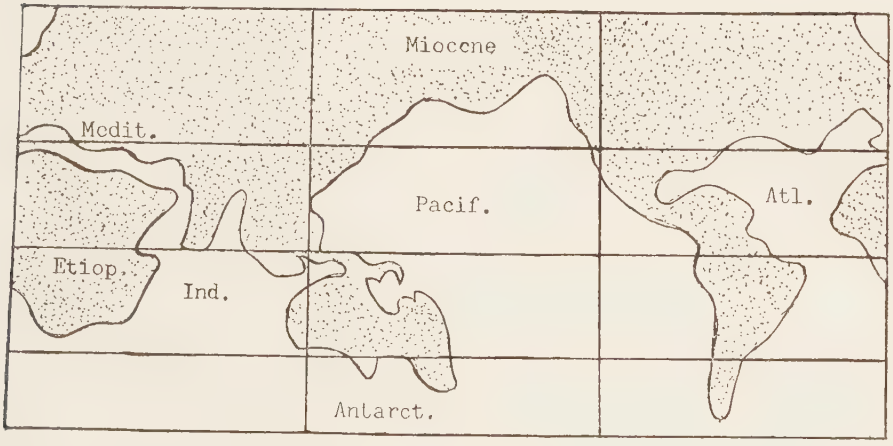

Middle Cretaceous
Medit.
Etiop.
Ind.
Pacif.
Atl.
Antarct.

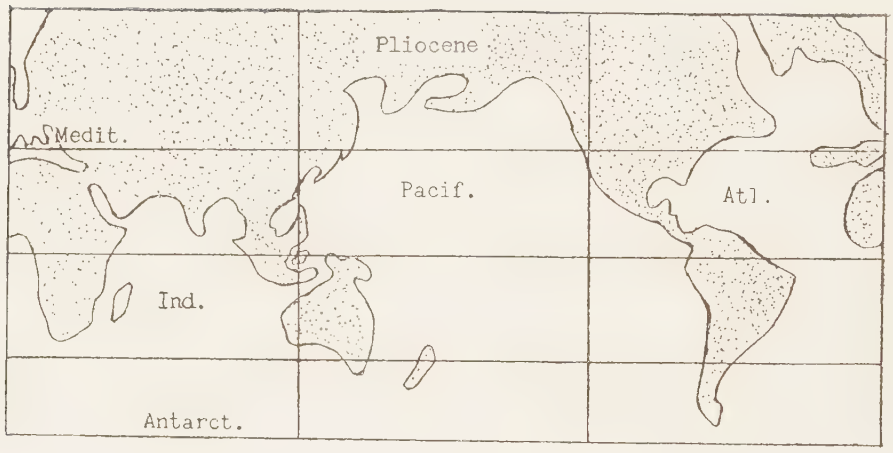

Upper Cretaceous
Medit.
Etiop.
Ind.
Pacif.
Atl.
Antarct.

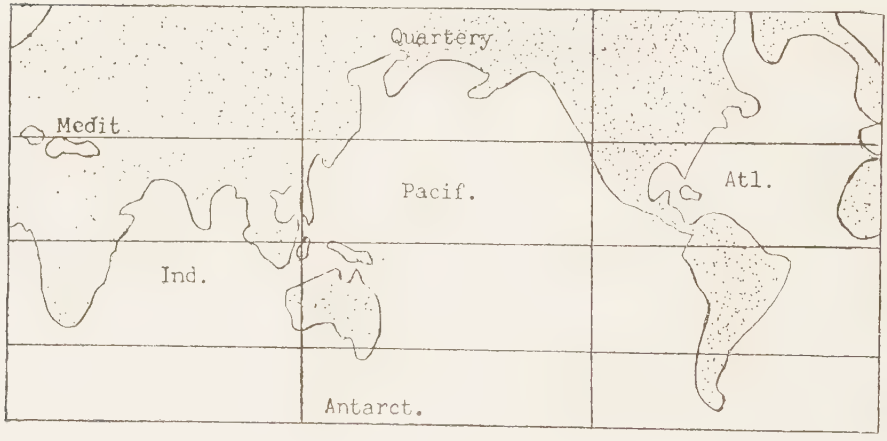

Lower Eocene
Medit.
Pacif.
Atl.
Ind.
Antarct.


Upper Eocene
Medit.
Pacif.
Atl.
Ind.
Antarct.


Oligocene
Medit.
Pacif.
Atl.
Ind.
Antarct.


Miocene
Medit.
Pacif.
Atl.
Etiop.
Ind.
Antarct.


Pliocene
Medit.
Pacif.
Atl.
Ind.
Antarct.


Quartery
Medit
Pacif.
Atl.
Ind.
Antarct.

THE DISTRIBUTION OF POLYCHAETES WITHIN THE INDO-PACIFIC

By G. A. Knox
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Polychaetes have not generally been regarded as being useful for the delimiting of zoogeographical regions. European workers when working up the results of collections from other regions were struck by the large percentage of European species that occurred among the material they studied. The percentage of cosmopolitan species in many regions is high when compared with other animal groups. In one of the areas involved in this study, 40% of the species can be classed as cosmopolitan. If these cosmopolitan species are eliminated from the lists a much clearer picture of the faunal relationships is obtained.

The majority of studies on Polychaete distribution have lumped together the shelf, benthal deep-sea, and pelagic faunas when considering relationships. In this study as far as possible only the shelf fauna has been considered. Difficulties were encountered as a large number of Polychaetes are eurybathic and species occurring only in deep water in one locality may also occur on the shelf. This is the first attempt to assemble distribution records for the polychaete fauna for an area as large as the Indo-Pacific. Wesenburg-Lund (1949) has recently summarized the distribution records for the Persian Gulf, Arabian Sea and Indian Ocean; and the relationships of the faunas of the East Indies, Philippines, Japan, Australia and New Zealand have been discussed by workers on collections made in these regions.

In such a survey as this there are so many difficulties that only very general conclusions concerning the nature of the distribution can be reached. In the first place in many areas there has been relatively little collection done. This applies particularly to the Pacific Islands. In the second place many of the collections have been selective rather than representative. From Table I it will be seen that from many areas a large number of Families are unrepresented. This applies particularly to small inconspicuous species such as the Syllidae. Some 30 species of Syllids have been recorded from the eastern temperate shores of Australia, while only two have been recorded from the adjacent tro-

pical northeastern shores. From central Polynesia (Fiji-Samoa) half of the 68 recorded species belong to one family, the Eunicidae.

For this study it was necessary to assemble the distribution records from more than 200 publications dealing with the Indo-Pacific region. The distributions of a total of 212 papers and monographs have been listed. Unfortunately 32 papers were not available. Most of these dealt with the East Indian region and the information for this area is incomplete as is that for northern Japan. There are also minor deficiencies for the information from Hawaii and the Philippines. For the other areas the information is more or less complete, and it is felt that the deficiencies do not detract from the general picture.

For the purpose of this study the Indo-Pacific has been divided into the following 24 areas:

1. The Red Sea.
2. The Arabian Sea.
3. Ceylon.
4. The Bay of Bengal.
5. The Malay Archipelago. The group of islands extending from the Malay Peninsula to New Guinea, excluding the Philippines.
6. The Philippines.
7. The South China Sea.
8. Southern Japan, from Formosa to 36°N. on the oceanic side of Japan.
9. Northern Japan, including the Sea of Japan.
10. The Hawaiian Islands.
11. Micronesia-Melanesia. The tropical Pacific Islands north of 10°S.
12. Central Polynesia. The Fijian and Samoan Islands.
13. Eastern Polynesia. The Pacific Islands east of 165°W.
14. The Kermadec Islands.
15. Northern New Zealand. The New Zealand shores north of East Cape.
16. Southern New Zealand.
17. New Caledonia.
18. Southern Australia, from 37°27′S. on the east coast to Kangaroo Island, including Tasmania.
19. Eastern Australia. The east coast from 26°S. to 37°20′S.
20. Northeastern Australia, from 26°S. to Torres Strait.
21. Northwestern Australia, from Torres Strait to 28°47′S.
22. Southwestern Australia, from 28°47′S. to Kangaroo Island.
23. The Indian Ocean.
24. Kerguelen.

In assembling the records synonymies were eliminated as far as possible and doubtful species were omitted. From the records a distribution table was prepared. When completed the list contained 1,367 names. Table I shows the number of species recorded in the more important Families from the above areas.

The majority of the species belong to the families Polynoidae, Nereidae, and Eunicidae. The abundance of representatives of the Family Eunicidae in tropical waters has often been commented upon and is confirmed by the results of this survey. Thirty-three species are recorded from Fiji-Samoa, 20 from Northern New Zealand, 16 from Southern New Zealand, while only four have been recorded from the Sub-Antarctic Islands.

From the general distribution table a second table (Table II) was prepared to show the number of species common to each two of the 24 divisions. For the purposes of this table cosmopolitan species have been neglected.

A study of this table shows that areas 1, 2, 3, 4, 5, 6, 7, 8, and 23 have a large number of species in common, indicating a large Indo-Malayan element. The Pacific Islands show affinities both with Australia and Indo-Malaya. The New Zealand area has many species in common with Australia, especially the southern and eastern coasts. The tropical coasts of Australia show strong affinity with the Indo-Malayan region as well as relationships with the temperate Australian regions. Kerguelen has 14 species in common with Southern New Zealand and only three that are also found in the Indian Ocean.

In order to gain a clearer picture of the distribution it was decided after an examination of the general distribution table to divide the species into a number of groups and plot their occurrence in each area (Table III). The groups of species recognized are as follows:

1. Cosmopolitan.
2. Endemic.
3. Circum-tropical.
4. Indian. Species characteristic of areas 1, 2, 3, 4, and 23.
5. Malayan.
6. Indo-Malayan.
7. Japanese.
8. Northern Pacific.
9. Indo-Pacific. Species ranging throughout areas 1–23 but not extending to tropical America or Antarctica.
10. Tropical Pacific.
11. Australasian.
12. New Zealand.
13. Antarctic.

A distribution pattern emerges from a study of Table III. The circumtropical group of species comprises a small element (0%–6%) scattered fairly evenly throughout all areas. A group of Indian species centered in the Bay of Bengal is well marked. This Indian element comprises only 2% of the Malayan fauna and a small percentage (0% – 6%) of the other areas to the west. The Malayan element is small comprising 9% of the species of the Malay Archipelago, again with scattered representatives to the west and south. An important Indo-Malayan element has its centre in the Malay Archipelago where it comprises 26% of the fauna. As one moves away from this centre the Indo-Malayan element becomes progressively less important, ranging from 7% for the Philippines to 0% for Polynesia.

There is a large group of wide ranging Indo-Pacific species. This element comprises 27% of the fauna of Micronesia-Melanesia and 10% to 26% of the fauna of all areas except Japan and Hawaii where it makes up 6% of the fauna. A well-defined Australasian group of species can also be recognized. An Antarctic element is important in the New Zealand fauna where it comprises over 20% and is also well represented in the southern parts of Australia.

The endemic element in Ceylon (1%) and the Indian Ocean (6%) is very weak. This is conjunction with the very similar percentage composition of the faunal elements of areas 2, 3, 4 and 23 would indicate that these areas form an Indian region with a fairly uniform fauna. The Arabian Sea could perhaps form a separate region with the Indo-Malayan element not as well represented as in other parts of the Indian region.

The Malay Archipelago appears to form a separate region with an endemic element of 37 species (16%). This endemic element is certainly considerably larger than this as the information for this region is incomplete. A Malayan element with scattered representatives to the south and west comprises 9% of the fauna. This region is also characterized particularly by the large number of Indo-Malayan species, 59 forming 26% of the fauna.

The Philippines also forms a distinct region with a large endemic element of 71 species (36%). Other species components are Circumtropical, 4 (2%), Indian 13 (7%), Malayan 8 (4%), Indo-Malayan 14 (7%), Japanese 5 (2%), Indo-Pacific 32 (16%) and Tropical Pacific 8 (4%). The Indo-Malayan element is small when compared with the adjacent Malay Archipelago. The species composition of the South China Sea area is essentially the same as the Philippines, although the Japanese element is larger, 9% compared to 2%. Of the 102 non-

cosmopolitan species listed for this area 30 are also found in the Philippines.

Southern Japan has a distinctive fauna with 117 endemic species (34%), the largest endemic element of any of the areas. Cosmopolitan species comprise 24% of the fauna (71 species), the Japanese element 11% (36 species) and the Indo-Pacific element 7% (21 species). Northern Japan also has a distinctive fauna with 35 endemic species (29%), 28 Japanese species (23%) and 12 Northern Pacific species (10%). Annenkova (1938, quoted by Hartman, 1948) lists 272 species for the northern part of the Japanese Sea. Of these 36% are warm water species, 23% are Artic-boreal, 11% are western Pacific and 11% are Arctic species.

The Hawaiian polychaete fauna is incompletely known and, as Edmondson (1940) states, the large population of reef dwellers remains to be investigated. Of the 66 species listed 28, or 43%, are endemic. From what is known it would appear that the relationships are with the Northern Pacific, Japan and Indo-Malaya rather than with the tropical Pacific.

The fauna of the tropical Pacific Islands, areas 11, 12 and 13, is also very incompletely investigated. Fiji-Samoa shows a large endemic element but most of these belong to one family, the Eunicidae. A group of tropical Pacific species is also important in all three areas. The endemic element is small (9%) in the Micronesia-Melanesia area and in the Indo-Pacific large (27%). When more information is available it is probable that this area will form one division of the tropical Pacific and Polynesia another.

Of the 20 non-cosmopolitan species reported from the Kermadec Island only 4 have also been recorded from New Zealand. The relationships of these islands would appear to be with the tropical Pacific and with Indo-Malaya.

The composition of the two New Zealand areas is so similar that separation is not justified. Of the 116 non-cosmopolitan species listed for southern New Zealand 67 have also been recorded from the northern portion. If these two areas were grouped, the endemic element would form 31% and the Antarctic element 22% of the fauna. There is also an Australasian element of 10% and an Indo-Pacific element of 12%.

New Caledonia closely resembles tropical Northeast and Northwest Australia. It resembles Northeast Australia in that in both the Australian element is small, 7% in the former and 9% in the latter, and the Indo-Pacific element is large, 26% in the former and 23% in the latter. Of the 58 non-cosmopolitan species listed for this area 25 have

also been reported from the Malay Archipelago, 20 from Northeast Australia and only 12 from each of Northeast and East Australia. Tropical Northeast Australia is more closely related to Indo-Malaya than to the Australian coasts to the south, having 21 non-cosmopolitan species in common with the Malay Archipelago and only 11 with East Australia.

Northwest Australia also shows close relationships with Indo-Malaya but has a larger Australasian element than the northeast coast. The temperate coasts of Australia, areas 18, 19 and 22, closely resemble each other and have a large number of species in common. They all have an important Antarctic element, 12% for South Australia, 11% for East Australia, and 17% for Southwest Australia.

Kerguelen is characterised by the large Antarctic element, 50%. Of the 41 non-cosmopolitan species 14 are also found in Southern New Zealand and only 3 in the Indian Ocean.

Tentatively on the basis of polychaete distribution the Indo-Pacific can be divided into the following regions: Indian, with possibly a separate Arabian Sea region; Malayan; Philippine, including the South China Sea; Southern Japanese; Northern Japanese; Hawaiian; Tropical Pacific, with a possible division into two areas by the 10°S. parallel; tropical Northeast Australia; tropical Northwest Australia; temperate South Australia; New Zealand; Kerguelen. Much more collecting, especially in the tropical Pacific, is required before the details can be worked out.

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TABLE I

NUMBER OF SPECIES IN THE MORE IMPORTANT FAMILIES FOR EACH AREA

	Red Sea	Arabian Sea	Ceylon	Bay of Bengal	Malay Archipelago	Philippines	South China Sea	Southern Japan	Northern Japan	Hawaiian Islands	Micronesia-Melanesia	Central Polynesia	Eastern Polynesia	Kermadec Islands	North New Zealand	South New Zealand	New Caledonia	South Australia	East Australia	Northeast Australia	Northwest Australia	Southwest Australia	Indian Ocean	Kerguelen
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Aphroditidae	1	1	3	6	6	3	1	9	6	1	0	0	0	0	2	2	0	3	2	6	1	1	7	1
Polynoidae	16	5	11	23	34	30	14	39	14	4	7	6	6	4	7	8	10	16	12	12	12	10	22	4
Sigalionidae	5	4	5	4	1	7	2	10	1	0	5	2	1	1	3	1	0	2	4	5	1	1	6	1
Polyodontidae	0	2	2	4	1	3	1	4	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0
Chrysopetalidae	2	1	0	1	1	1	1	1	0	0	0	0	2	0	2	0	0	0	1	0	1	2	1	1
Amphinomidae	6	9	2	14	18	9	7	8	1	6	6	10	3	3	4	2	2	4	1	4	6	3	11	0
Hesionidae	4	0	3	6	5	6	5	2	0	1	6	3	2	0	1	1	1	2	2	5	4	1	5	1
Phyllodicidae	9	2	8	10	6	8	4	13	3	3	2	6	6	2	8	6	4	4	5	2	10	3	11	2
Syllidae	16	6	5	7	8	6	5	14	1	1	4	0	13	1	19	11	10	6	31	2	14	21	13	7
Neridae	26	7	11	28	42	29	37	28	11	19	6	5	7	4	13	11	17	9	11	9	26	14	24	1
Eunicidae	41	26	19	19	32	27	22	36	8	12	14	33	6	7	20	16	12	15	21	10	27	16	26	3
Nephtyidae	2	2	1	5	5	4	0	2	1	0	0	0	0	1	3	3	0	2	2	0	1	1	1	1
Glyceridae	8	2	6	12	5	6	3	11	9	1	3	0	1	0	3	4	2	2	3	2	0	0	4	1
Goniadidae	0	0	1	3	0	0	0	3	3	0	0	0	0	0	1	4	0	1	2	1	0	0	0	0
Ariciidae	1	1	0	6	0	1	2	3	3	0	0	0	0	1	4	3	0	0	2	0	0	2	2	1
Spionidae	4	2	2	5	1	2	2	11	11	0	0	0	0	0	3	7	0	0	3	1	1	0	1	0
Opheliidae	4	2	3	4	0	3	5	1	5	2	1	2	0	0	3	3	3	2	2	1	2	2	4	1
Chaetopteridae	1	2	2	1	0	1	1	5	1	0	1	0	0	0	1	1	1	1	1	0	2	1	2	0
Flabelligeridae	1	8	2	3	1	2	2	3	3	1	1	0	0	1	2	2	1	3	5	1	1	1	1	2
Capitellidae	3	2	3	7	1	2	3	3	1	0	2	0	0	0	1	2	4	0	2	1	1	1	4	0
Cirratulidae	3	6	3	2	5	3	4	11	5	2	2	0	0	0	3	5	3	1	3	0	1	1	1	2
Maldanidae	7	4	0	10	16	3	1	8	3	0	0	1	0	0	7	8	0	2	2	1	0	1	6	2
Pectinariidae	1	2	1	1	1	6	0	1	1	0	1	0	0	0	1	1	2	1	1	2	0	1	1	1
Sabellariidae	1	1	2	1	6	4	0	6	1	1	1	1	0	0	4	1	0	2	4	1	1	1	3	3
Ampharetidae	1	3	1	5	0	4	0	3	1	0	0	1	0	0	2	2	1	1	3	2	2	0	2	1
Terebellidae	21	11	13	6	7	13	9	33	14	5	6	2	0	2	8	13	4	6	7	4	5	4	8	6
Sabellidae	16	6	4	5	13	11	8	22	10	5	5	2	0	1	7	8	4	2	6	2	6	4	4	3
Serpulidae	18	11	6	13	15	3	3	16	5	1	3	3	0	1	10	12	2	6	9	8	8	6	8	4
TOTAL	218	128	119	211	230	197	142	306	123	65	76	77	47	29	142	137	83	94	147	83	134	98	178	49

TABLE II

NUMBER OF SPECIES COMMON TO EACH OF TWO AREAS THE ELIMINATION OF COSMOPOLITAN SPECIES

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	No. of Non-Cosmopolitan Species
Red Sea	1	..	37	43	44	45	35	36	35	12	6	17	8	7	2	10	13	28	18	20	14	35	19	49	3	139
Arabian Sea	2	..	..	35	36	26	26	23	20	5	8	9	4	4	0	8	10	14	11	11	11	23	9	29	5	82
Ceylon	3	..	..	..	32	37	33	27	29	9	6	15	10	5	3	8	8	16	16	12	13	25	7	36	2	82
Bay of Bengal	4	..	..	..	..	57	34	33	35	8	7	13	6	4	0	14	11	15	18	17	16	21	8	45	2	150
Malay Archipelago	5	..	..	..	..	..	46	39	33	11	4	22	17	9	6	15	18	25	18	16	21	31	16	48	3	169
Philippines	6	..	..	..	..	..	..	30	31	19	7	12	19	9	3	11	10	16	15	18	19	29	11	27	3	157
South China Sea	7	..	..	..	..	..	..	..	36	12	5	12	5	5	0	5	6	17	12	12	11	22	6	29	3	102
Southern Japan	8	..	..	..	..	..	..	..	..	32	9	15	7	5	2	8	11	17	12	13	12	18	11	26	4	237
Northern Japan	9	..	..	..	..	..	..	..	..	..	1	3	4	1	2	4	5	5	5	4	3	8	3	8	2	90
Hawaiian Islands	10	..	..	..	..	..	..	..	..	..	..	5	2	3	0	2	2	4	4	4	3	3	4	3	0	52
Micronesia-Melanesia	11	..	..	..	..	..	..	..	..	..	..	..	8	5	1	5	6	15	12	10	13	14	5	16	0	54
Central Polynesia	12	..	..	..	..	..	..	..	..	..	..	..	..	4	5	3	3	4	3	3	5	8	5	9	0	60
Eastern Polynesia	13	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1	1	4	2	5	5	5	5	6	1	34
Kermadec Islands	14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4	4	2	3	4	3	6	4	2	1	20
Northern New Zealand	15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	67	9	25	32	13	29	26	18	10	121
Southern New Zealand	16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	14	25	28	7	25	19	18	14	116
New Caledonia	17	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	13	12	12	20	13	22	1	58
South Australia	18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	38	13	25	28	16	2	72
East Australia	19	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	11	36	32	26	6	110
Northeast Australia	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	16	17	2	66
Northwest Australia	21	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	28	26	5	96
Southwest Australia	22	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8	4	68
Indian Ocean	23	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	106
Kerguelen	24	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	41

TABLE III

	Red Sea	Arabian Sea	Ceylon	Bay of Bengal	Malay Archip.	Philippines	South China S.	Southern Japan	Northern Japan	Hawaiian Isls.	Micronesia-Mel.	Central Polyn.	Eastern Polyn.	Kermadec Islands	North New Zeal.	South New Zeal.	New Caledonia	South Australia	East Australia	Northeast Aust.	Northwest Aust.	Southwest Aust.	Indian Ocean	Kerguelen
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Cosmopolitan	82	51	39	64	61	41	39	71	31	14	24	9	13	9	25	26	26	24	40	18	42	31	74	9
Percentage	37	38	33	30	27	20	27	24	26	21	31	13	28	31	18	18	30	25	26	23	30	31	40	18
Endemic	40	19	1	31	37	71	26	117	35	28	7	30	19	6	26	26	11	6	27	19	17	8	6	11
Percentage	18	14	1	14	16	36	18	34	29	43	9	43	40	21	18	18	13	7	18	23	12	8	3	22
Circum-tropical	6	6	6	13	10	4	6	12	2	6	4	0	3	0	1	0	3	3	3	3	3	1	6	1
Percentage	3	5	5	6	4	2	5	4	1	9	5	—	6	—	—	—	3	3	2	3	2	1	3	2
Indian *	41	24	31	48	4	13	9	18	2	1	5	2	2	0	3	1	5	4	6	2	6	4	29	2
Percentage	19	18	26	22	2	7	6	6	1	2	6	2	4	—	2	—	5	4	4	2	4	4	16	4
Malayan †	0	0	0	0	21	8	4	3	0	1	2	4	2	1	0	0	2	2	4	1	1	2	0	0
Percentage	—	—	—	—	9	4	3	1	—	2	3	6	4	4	—	—	2	2	3	1	1	2	—	—
Indo-Malayan *	23	12	21	30	59	14	14	10	0	0	0	1	0	1	2	3	2	4	4	3	11	3	31	2
Percentage	10	9	17	14	26	7	10	3	—	—	—	1	—	4	1	2	2	4	3	4	7	3	12	4
Japanese *	0	0	0	0	0	5	13	36	28	1	0	1	0	0	1	1	0	0	0	1	1	0	0	0
Percentage	—	—	—	—	—	2	9	11	23	2	—	1	—	—	—	—	—	—	—	1	—	—	—	—
Northern Pacific *	0	0	0	0	0	1	0	10	12	6	2	1	1	0	1	0	0	0	0	0	0	0	0	0
Percentage	—	—	—	—	—	—	—	3	10	9	3	1	2	—	—	—	—	—	—	—	—	—	—	—
Indo-Pacific	29	21	22	28	31	32	24	21	7	4	21	8	5	5	19	17	22	24	21	19	25	12	24	0
Percentage	13	16	18	13	13	16	17	7	6	6	27	12	10	17	13	12	26	25	14	23	19	12	18	—
Tropical Pacific †	0	0	1	0	4	8	4	5	1	6	13	8	1	1	3	4	4	5	4	5	2	1	1	0
Percentage	—	—	1	—	2	4	3	2	1	9	17	12	2	4	1	3	5	5	3	6	1	1	—	—
Australasian *	0	0	0	0	2	0	1	1	0	0	3	2	1	3	18	13	6	12	23	8	18	18	1	1
Percentage	—	—	—	—	1	—	—	—	—	—	3	2	2	10	12	9	7	12	15	9	13	18	—	2
New Zealand *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	19	0	0	1	0	0	1	0	0
Percentage	—	—	—	—	—	—	—	—	—	—	—	—	—	—	13	13	—	—	—	—	—	—	—	—
Antarctic *	0	0	0	0	1	1	1	3	3	0	0	0	0	4	29	32	3	12	17	5	12	17	0	25
Percentage	—	—	—	—	—	—	—	1	2	—	—	—	—	14	20	23	3	12	11	6	9	17	—	50
Total	221	133	121	214	230	198	141	307	121	67	81	66	47	30	148	142	84	96	150	84	138	98	172	51
Non-Cosmopolitan	139	82	82	150	169	157	102	237	90	52	54	60	34	20	121	116	58	72	110	66	96	68	106	41

* Appear to be discrete regions.
† Not too precise.
Indian and Indo-Malayan, Japanese and Northern Pacific, and Australasian, New Zealand and Antarctic regions are continuous areas.

A NEW APPROACH TO THE DISTRIBUTION OF FISHES IN THE INDO-WEST PACIFIC AREA

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Much has been written on the distribution of marine fishes of the Indian and Pacific Oceans. Roughly ichthyologists classify the marine ecological habits into three categories, shore, pelagic, and deep-sea. Although these groupings are useful there is a considerable overlap between the zones and their limits vary in different seas.

Shore fishes are those that occur over the continental shelf or along the coastal areas, and around the shores of islands; as adults, normally not far out to sea, and usually in depths shallower than 600 feet. Most typical deep-sea fishes live in the stratified subsurface layers of the sea and because of the uniformity of temperature and salinity in these areas, they may have an almost world-wide distribution.

The marine shore fishes may be divided into two main regions: tropical and temperate. The tropical shore fauna extends around the world but is definitely restricted by temperature. The temperate fauna may be subdivided into: North Pacific, North Atlantic and Temperate South Pacific.

The circumtropical marine shore fauna may be divided into two main regions: Indo-West-Pacific and West-Atlantic-East Pacific.

The richest marine shore fauna of the world is that of the tropical Indo-West-Pacific containing, with but few exceptions, representatives of all known living tropical shallow-water marine fish families and a very high percentage of all the genera occurring in other tropical regions.

The geographical boundaries of the tropical Indo-West-Pacific shore fauna are in general the region from the head of the Red Sea southward along the African coast to Natal, thence eastward including island groups and coastal regions of Southern Asia, northward to the Ryukyu Islands and Southern Japan, southward to Northern Australia, the Great Barrier Reef and New Caledonia, thence eastward to the Tuamotu Islands and Easter Island, northwestward to include the Hawaiian Islands. Although the boundaries of this region are ill-defined the fauna is mostly restricted to coral reefs.

The tropical West-Atlantic-East Pacific shore fauna in the Pacific extends from the Gulf of California and Lower California southward to Ecuador and the very northern part of Peru, including the adjoining offshore Clipperton, Cocos, and Galapagos Islands.

Statements that the tropical East-Pacific shore fauna is trenchantly distinct from the Indo-West Pacific are only partly correct. It is true that the West-Atlantic-East Pacific has a very high percentage of distinct endemic species, but there is a substantial percentage of species very closely related, some the same, others of the subspecies level, common to both regions—on the generic level there is a high percentage of genera and subgenera common to both regions. This condition of closer relationship is more pronounced in some families than in others, and in a few families the close relationships are lacking. They are closer in the Clipperton and Cocos Islands than along the Pacific American shores.

The statements by Zoogeographers as summarized by Ekman (Zoogeography of the Sea, pp. 15–16, 1953) on the great distinctness of this eastern Pacific fish fauna has been based to some extent on misinformation. This has resulted from studies by ichthyologists who have confined their observations to limited faunal areas, resulting in conclusions based on local faunistic concepts. There has never been published a single paper comparing the genera or species common to these major faunal areas. Too many systematic ichthyologists are individualistic and have created numerous generic and specific names based only on differences for the fishes of their local faunas. The result therefore is to magnify differences by means of different names on the generic and specific level whether important structural differences do or do not exist. Zoogeographers base their differences between faunal areas to a large extent on the percentage of different generic and specific names occurring in faunal check-lists. Too many of these check-lists are prepared by ichthyologists who know only their local faunas, and have never had an opportunity to study widely ranging species and genera. This lack of comparison of the wide-ranging species in wide-ranging genera, and of genera in wide-ranging families, tends to cause zoogeographers to establish barriers that exist to some extent in scientific names only.

For example, conclusions have been made on the basis of the 1928 "Check-list of North and Central American Fishes" by Jordan, Evermann and Clark. Ichthyologists are nearly unanimous in their opinion that the check-list elevated hundreds of subgenera to generic level and numerous genera to sub-family level. Thus when this check-list is compared with others of a still more local faunal concept the number of "distinct genera" by name is greatly multiplied.

Since there are practically no careful comparisons of the wide-ranging species and genera common to these major faunal regions too much significance has been given to different scientific names, which show neither relationship nor differences. Careful comparisons have not been made in a sufficient number of examples.

I am fully aware of the almost non-existence of coral reefs in the eastern tropical Pacific and the Marquesas Islands since perhaps the time of the Tethys Sea. Ecological conditions are not wholly suitable in the eastern Pacific for a typical coral reefs fauna because of the massive upwelling of relatively cold water. In addition there are few island "stepping stones" forming a suitable habitat.

Within the tropical Indo-West-Pacific region, in spite of the homogeneity of the fauna, occur several subfaunas. Although extensive professional ichthyological collecting and study has been somewhat limited, enough has been accomplished during the last 50 years to indicate certain island groups and regions as containing distinctive endemic species and subspecies. Roughly these regions are: (1) East Africa, Red Sea, Madagascar and Mauritius; (2) East Indies to Northern Australia and the Great Barrier Reef to the Philippines; (3) Ryukyu Islands and southern Japan; (4) Hawaiian Islands and Johnston Islands; (5) Marianas, Marshalls, Gilberts, Line Islands, Phoenix and Samoa Islands and perhaps others; (6) The Marquesas and Tuamotu Archipelago. Other island groups may be distinctive, too, but to prove it more careful ichthyological revisional analysis of species will need to be made.

My comparative studies of wide-ranging genera, species and subspecies in the tropical Indo-West-Pacific and Eastern Pacific indicate a much closer relationship of these faunas than has been stated by zoogeographers. As might be expected on the generic level the relationship is very close, but on the species and subspecies levels there are distinctnesses between Eastern and Western Pacific. Among the Island groups of the Indo-West-Pacific the differences show up strongest on the subspecies and racial level. This new approach or concept requires careful analysis of species and of genera on a world-wide revisionary basis.

Widely ranging species (used on a broad concept, perhaps superspecies) extending from the Pacific American shores to the east coast of Africa, when studied intensively with the use of statistical methods, color photographs of living fishes and basic color patterns of preserved specimens, reveal that some of these so-called species actually are composed of two or more species, subspecies or races each more or less inhabiting subfaunal areas.

To illustrate this concept I give herewith a few examples: Family Acanthuridae, surgeon fishes; *Acanthurus triostegus* ranges from Pacific American region of Clarion, Clipperton and Cocos Islands to the African east coast. *A. triostegus triostegus* (Linnaeus) has the color pattern consisting of a single dark spot at base of pectoral and this form occurs from the Indian Ocean to the American Pacific with the exception of the Central Pacific and the Hawaiian Islands. *A. t. marquesensis* occupies the Marquesas Islands, whereas *A. t. sandvicensis* occupies the Hawaiian Islands.

The family Labridae has a so-called wide-ranging species known in the literature as *Thalassoma duperry*. My studies of specimens indicate that *T. lucasanum* of the American tropical Pacific is closely related to *T. duperry* of the Hawaiian Islands and that *T. marnae* of the central equatorial Pacific differs only statistically from *T. lucasanum* and represents a subspecies. Thus *T. duperry* and *T. lucasanum* may be recognized by slight difference in coloration of head and median fins. *T. lucasanum* normally averages 13 branched pectoral rays whereas *T. dupery* has 14. Now *T. l. lucasanum* averages 1 to 2 gillrakers fewer than *T. I. marnae.*

Another common labrid *Halichoeres hortulanus,* formerly consid_ered to range throughout the tropical Indo-West Pacific, actually represents to subspecies or perhaps full species. *H. hortulanus* of the tropical West Pacific differs from *H. centriquadrus* of the East African region by lacking a small black caudal spot, always present in *H. hortulanus.*

The Moray eels have similar color differences, for example, the common *Echidna nebulosa* (Ahl) of the tropical Indo-West-Pacific is represented by a subspecies or population at Cocos Island in the American Pacific by *E. cocosa* German, which is differentiated by the blackish bars meeting more fully on the abdomen than for nebulosa. Another eel genus, *Uropterygius* shows similar close relationships of its numerous species between the American tropical Pacific and the tropical Indo-Pacific.

Ichthyologists have scarcely begun the study of the relationships of the named genera and species in the vast tropical shore faunas of the three oceans. As evidence gradually accumulates, I predict that more and more subfaunal areas will be established in the species and subspecies level but closer relationships will appear on the generic level, if the generic concept continues to include a group of closely related species.

THE ZOOGEOGRAPHICAL DISTRIBUTION OF THE INDO-PACIFIC LITTORAL HOLOTHURIOIDEA

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Introduction

Ekman in his Zoogeography of the Sea (1953) used "shelf fauna" for "littoral" in its widest sense. The terms "shore fauna" and "coastal fauna" according to Ekman are frequently used by both English and American authors, but are not fully adequate to convey the lower limits of the fauna in question. The littoral holothurioidea referred to in this paper do not cover the entire shelf holothurian fauna of a sea-floor to a depth of about 200 meters. The present study of the littoral forms of Holothurioidea is confined only to the species recorded from a depth not exceeding 50 fathoms, approximately half of the depth of Ekman's shelf fauna.

The Zoogeographical Division of the Indo-Pacific Ocean

Ekman divided the warm-water fauna of the shelf into two main regions: the *Indo-West-Pacific* and the *Atlanto East-Pacific-areas*. Each of the two main regions is subdivided into sub-regions. Although it is possible to distinguish several sub-regions, the present incomplete knowledge of faunistic facts does not allow as yet any precise delimitation of the various sub-regions. For this reason, we may subdivide the entire Indo-Pacific region into ten distinct provinces, namely; the North Pacific, South Pacific, East Pacific, West Pacific, Northwest Pacific, Southwest Pacific, Northeast Pacific, Southeast Pacific, Central Pacific and the Indian Ocean. The Indo-West-Pacific of Ekman comprises the Indian Ocean, West Pacific (warm waters), Northwest Pacific (warm and cold waters), Central Pacific (warm waters), and Southwest Pacific (warm and cold waters). The Atlanto-East-Pacific comprises the East Pacific (warm waters), Northeast Pacific (cold waters), Southeast Pacific (cold waters) and the Atlantic Ocean (warm and cold waters). The two other provinces, the North Pacific and South Pacific, may be regarded as part of the polar areas.

The Holothurian Fauna of the Different Provinces of the Indo-Pacific Ocean

Table I lists many of the known littoral holothurians reported from the different provinces of the Indo-Pacific Ocean. The Indo-West-Pacific area has related and almost identical species of Holothurioidea. The explanation of the close relationship and similarities of the aspidochirote holothurian fauna of this particular area is the proximity of the different provinces with their continental shelves almost connecting with one another. The Indo-Malayan region (Indian Ocean, West Pacific and Southwest Pacific provinces) has its faunistic centre in the Malay Archipelago. The Indo-Malay Archipelago is the world's greatest archipelago containing large water areas less than 200 meters in depth. There is no other region in the world richer in species than this particular area, and it is considered to be the "hotbed" of echinoderms including all other marine life. Farther eastward the number of known species of Holothurioidea lessens due apparently to the absence of more records of species from the place. Various investigators report that the marine life toward the east is poor compared with that of the westward side of the Pacific, although others believe the contrary with regard to fishes. One of the reasons advanced for this finding is the direction of the main currents, which are from east to west.

The Hawaiian echinoderm fauna, according to H. L. Clark and W. K. Fisher, is closely related and identical to those of the isolated oceanic islands the farther to the east they are situated. The affinity of Hawaii's fauna with the American shelf fauna, to which the fauna of the Galapagos Islands belongs, is the same as with that of the Polynesian fauna. The fauna of the Galapagos has been grouped with that of Hawaii and outer Polynesia as "Eastern Polynesian" fauna.

The tropical and partly subtropical faunistic region of Australia is contrasted with a temperate one. The number of species is not as large in the tropical shelf region of Australia as in the Indo-Malayan region but many species are nevertheless common to both. Many species of Holothurioidea are endemic in Australia, but they belong as a whole to genera which are also represented in the Indo-Malayan fauna.

The Atlanto-East-Pacific is the second great warm-water region of the warm-water fauna of the shelf. Table I also lists many species of holothurioidea common to both the tropical East Pacific and the West Atlantic Ocean. Ekman considered the two fauna as a faunistic unit, in spite of the presence of physical barrier, the isthmus of Panama. The affinity between the two marine regions is shown not only by the holothurian fauna but other marine life including the fishes. To explain the close faunistic resemblance between the two coastal regions which

are separated by land barrier, Ekman postulated a direct connection in the past between the two regions. This direct connection of the two oceans has been corroborated by paleontological and geological evidences. It has been shown that for long periods of the Palaeozoic and Mesozoic eras the Pacific had a direct connection with the Atlantic across the present Central America. This was changed in the Tertiary period. Again in the Eocene, Oligocene and Miocene the two oceans had a direct connection for considerable period which, according to Schuchert, has existed without interruption. This accounts for the many identical forms of holothurians and other marine life in the two oceans.

The holothurians common to both tropical waters of the two oceans are said to be circumtropical. Holothurians recorded from the West Pacific, Central Pacific, East Pacific, Indian Ocean and the Atlantic Ocean are circumtropical in distribution. The occurrence of identical species around the tropical warm waters may be understood if the geological history of the past is reviewed. It is said that across the greater part of our planet an immense sea once stretched, mainly in an easterly and westerly direction, dividing the continents into two main groups, a southern and a northern group. It connected the East Pacific, the Central Atlantic, the Mediterranean, the Indian Ocean and the West Pacific with one another. According to Suess this extensive sea in the remote past was known as "Tethys", the name of the wife of the God Okeanos. Other names given to this sea are Mediterranic, Mesozoic Mediterranean, Numulite Sea, Mesogee, etc. During the whole of the Mesozoic era and the early Tertiary Period, the Tethys Sea was of considerable size. The Indo-West Pacific, the Mediterranean, the tropical Atlantic and East Pacific faunas were, therefore, parts of one major unit, the Tethys fauna. To understand the present warm-water fauna therefore, it is of great importance to know the former Tethys fauna thru paleontological studies.

One of the most interesting facts is that the early Tertiary Atlantic fauna had a distinct Indo-West-Pacific character similar particularly to that of the Mediterranean fauna. Many groups of marine animals now found confined to the Indo-West-Pacific have also been found to have existed in the East Atlantic Ocean. Although there was no holothurian reported among the echinoderms because they do not usually fossilize, the present holothurian fauna shows several of them to be circumtropical. We may cite a couple of them to illustrate the existence of identical species around the tropical waters of both oceans to give light to the existence of the Tethys Sea in the remote past. *Holothuria imitans* Ludwig and *H. difficilis* Semper are among the several circumtropical species listed. Their occurrence, particularly on both sides of

the Atlantic around the entrance to the Mediterranean and the Red Sea through the Indian Ocean, the West Pacific, Southwest Pacific and the Central Pacific, is a good evidence that these particular species were already existing in their present habitats long before the formation of the land barrier between the two American continents and that of Europe and Africa. With the land barriers now existing, it is hard to explain their circumtropical distribution through their pelagic auricularian larvae by way of the northern and southern tips of the different continents. It is more logical to believe the former existence of the Tethys Sea which connected the Indo-Pacific and the Atlantic oceans up to the Miocene of the Tertiary Period.

The intermigration of similar or identical species of holothurians within the Indo-Pacific area through their auricularian larvae is a possible explanation of the wide distribution of many of the species listed. Mortensen (1925) reported that in his observation on *Stichopus californicus* (Stimpson), the auricularian larvae after the third week still remained for some time without much differentiation. It is safe to speculate, therefore, that an auricularian larva may remain pelagic for some time before they settle down to start their sedentary life, hence it is possible for them to be carried by the current to distant places usually in an east to west direction. This also explains why there are more species of holothurian listed in the West Pacific, Southwest Pacific, and the Indian Ocean, which fact confirmed the findings of others that the Indo-Malayan region is the richest in marine life species.

Comparing the holothurian fauna known from the Atlanto-East-Pacific region with those of the Indo-West-Pacific, two distinct differences may be noted, namely, the entirely different species of the fauna and the predominance of the dendrochirote holothurians over the aspidochirotes. Although there are few species that are almost bipolar in distribution, yet the few known species from the western coast of South America are endemic to the place. The distinct differences of the holothurian fauna of the Southeast Pacific from that of the oceanic islands of the Central Pacific may be explained by the deep ocean barrier between them and the upwelling of cold bottom water along the southwestern coast of South America.

Among the few dendrochirotes from the southern tip of South America, *Psolus squamatus* (Koren) var. *segregatus* Perrier is also found in the Bering Sea of North America. The absence of this species in the East Pacific makes it a bipolar form and its bipolar distribution may be explained by the Relict Theory of Theel, Pfeiffer and Murray. This species apparently was formerly a cosmopolitan warm-water form and became extinct in the tropical regions for unknown reasons, or it

changed to a new form, thus leaving behind the northern and southern parts of this species as a relict.

The Ambonesian region, named after one of the Mollucca Islands of Amboina, has become renowned as the locality of pioneer investigations on the Malayan animal world. Although the Philippines is among the islands included in this region with the island of Luzon forming a triangle with Borneo and New Guinea within which groups of marine animals may serve as a zoogeographical indicator, the holothurian fauna has not been fully worked out. Carl Semper apparently is the pioneer in the study of Philippine Holothurioidea. Semper's list is not available although that of Seale with 66 different species were taken from Semper's Holothurioidea of the Philippine Archipelago. Not all the holothurioidea listed by Seale from the Philippines were encountered by the writer in his survey of the Echinoderm Fauna of Puerto Galera Bay and adjacent waters, the Basilan Channel around Zamboanga, the Sitankai Reefs of Sulu, the Taganak Barrier Reefs of the Turtle Islands, Coron Bay of Palawan, and the Hundred Islands and vicinity of Lingayen Gulf. Semper's materials were taken mostly from Bohol and vicinity. From the 66 species listed by Seale from Semper's record from the Philippines, 17 species were actually encountered by the writer, leaving 49 species not met yet. So far recorded by the writer from the different localities in the Islands are 48 different species excluding a couple of new species, 13 of which were listed in Seale's check list, leaving at least 35 species not included therein. Adding to the 48 species recorded by the writer the 49 species listed in Seale's list, which were not so far encountered, plus two new species, there will be, all in all, 99 species of littoral holothurians from Philippine waters. Based from the collection of the Allan Hancock Foundation which the writer had the opportunity of going over and identifying, not much is known about the holothurian fauna of the other places of the West Pacific except those of Guam and the Mariana Islands. The holothurian fauna of these islands, as identified by the writer, together with those from the Hawaiian islands of the Central Pacific, are identical in most cases with those of the Philippines. This is also what is to be expected from the other places of the West Pacific area.

The Indian Ocean (warm waters) comprises the area between eastern Africa and Western Australia and the East Indies, including the Arabian sea and the Bay of Bengal. Fortunately the holothurian fauna of the area has been worked out by several scientists. There are around 28 species of holothurians reported from South Africa represented in 10 genera, all but one of which are more or less cosmopolitan or at least tropi-cosmopolitan. Of the 28 species, 12 occur on the Australian coast,

but all are more or less common. The East African holothurian fauna is represented by 32 species of 14 genera. Of the 14 genera, all but one (*Patinapta*) occur in Australia. Of the 32 species, 24 occur in Australia. The same genera and most of the species also occur throughout the East Indian region. The natural explanation of the similarity between the East African and Australian holothurian faunas, according to H. L. Clark, is that each is a southern or southwestern extension of the East Indian fauna. All the Australian species concerned are found on the eastern coast, evidently migrants from the East Indies. The holothurians of the western coast do not resemble those of East Africa as much as those of the northern and northeastern coasts. The holothurians of the northwestern corner of the Indian Ocean comprising the Arabian area, including the Red Sea, the Gulf of Aden, and the Persian Gulf, according to H. L. Clark, have 38 species in a dozen genera, all of which except 1 or 2 of doubtful validity occur in Australia and throughout the East Indies. Around 16 species are endemic to the region which confirms the belief that the Arabian region has been more or less isolated for a long period.

Ceylon, which is somewhat nearer to northwestern Australia than is Mauritius, has around 51 species in contrast to only 28 from Mauritius. As far as species are concerned, only 10 of the species listed from Ceylon are reported as yet from Mauritius, but comparison with Australia shows 26 species in common. Of the Mauritian holothurians only 12 are Australian. In other words, 43 per cent of the Mauritian holothurians and practically 50 per cent of those in Ceylon also occur in Australia.

The East Indian area (Indo-Malay Archipelago) includes the entire West and Southwest Pacific with the eastern part of Indian Ocean, and is considered the "hotbed" of echinoderms, if not of all marine life. There are over 200 species of holothurians represented in some 40 or more genera. The genera of the East Indian and Australian holothurians are otherwise almost identical, according to the findings of H.L. Clark. The two small apodous genera *Anapta* and *Labidoplax* have not yet been found in Australia, whereas all Australian genera occur in the East Indies except the small apodous genus *Trochodota*. According to H. L. Clark, an examination of the list of species found in the two areas reveals that 83 species of the holothurians found in Australia are endemic. Of the remaining 76 species, 67 are East Indian, the remaining 9 being New Zealand or Pacific species. The Australian holothurians may then be said wtih certainty to be of East Indian origin.

From the findings of H. L. Clark and others, it has been pointed out that the East Indies is the place of origin of all the tropical Aspi-

dochirote holothurians that have spread all over the Indian Ocean and the Pacific areas. The over 200 species of holothurians reported from the East Indies with some 40 or more genera proved the above assertion. An area or province where there is the most number of species of animals is usually considered the place of origin of the said animals. Basing it from this hypothesis, we may also conclude that the East Pacific area, particularly the Gulf of California, is the place of origin of the Dendrochirote holothurians.

The North Pacific and South Pacific provinces, which are not included under the two main regions but which may be regarded closer to the polar regions, have the least number of holothurian fauna. The writer listed about a dozen species from the North Pacific and almost none from the South Pacific. (See chart). All the species recorded from the North Pacific are dendrochirotes and one single species of an apodous holothurian, whereas the two species from the South Pacific are aspidochirotes. None of these cold-water forms is endemic to the place. The unequal distribution of the North and South Pacific holothurian fauna is due to the unequal land masses and the differences in the expanses of the ocean. The North Pacific has great continental masses with almost continuous connections between the various temperate and arctic shelf regions, although it runs through climatically different regions. The South Pacific is the opposite of the North, with wide expanses of ocean separating the great shelf regions, and with large tracts of abyssal deep sea.

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TABLE I

THE ZOOGEOGRAPHICAL DISTRIBUTION OF THE LITTORAL INDO-PACIFIC HOLOTHURIOIDEA

ASPIDOCHIROTE HOLOTHURIOIDEA

SCIENTIFIC NAME	SYNONYM	NORTH PACIFIC	SOUTH PACIFIC	EAST PACIFIC	WEST PACIFIC	N.W. PACIFIC	S.W. PACIFIC	N.E. PACIFIC	S.E. PACIFIC	CENTRAL PACIFIC	INDIAN OCEAN	ATLANTIC OCEAN
Holothuria albiventer Semper					x		x				x	x
H. aculeata Semper					x		x					
H. altimensis H. L. Clark							x					
H. amulifera Fisher										x		
H. arenicola Semper	*Holothuria maculata* Brandt *H. rathbuni; Sporadipus (Acolpos) maculatus* Brandt; *Holothuria humilis* Selenka; *H. densipedes* H. L. Clark			x	x		x			x	x	x
H. arenicola var. *boutani* Herouard				x								x
H. argus (Jaeger)	*Bohadschia argus* Jaeger				x		x			x	x	
H. atra Jaeger	*Holothuria sanguinolenta* Bell; *H. raduckensis* Ch. & Eys.; *H. amboinensis* Semper; *H. atra* var. *amboinensis* Theel; *Halodeima atra* (Jaeger)			x	x	x	x			x	x	x
H. axiologa H. L. Clark							x					
H. bivittata Mitsukuri	*Holothuria (Bohadschia) bivittata* Panning				x	x						
H. bowensis Ludwig							x					
H. chilensis Semper				x					x			

SCIENTIFIC NAME	SYNONYM	NORTH PACIFIC	SOUTH PACIFIC	EAST PACIFIC	WEST PACIFIC	N.W. PACIFIC	S.W. PACIFIC	N.E. PACIFIC	S.E. PACIFIC	CENTRAL PACIFIC	INDIAN OCEAN	ATLANTIC OCEAN
Holothuria cinerascens (Brandt)	*Stichopus (Gymnochirota) cinerascens* Brandt; *Holothuria pulchella* Selenka				x		x			x	x	x
H. coluber Semper	*Holothuria pyxis* Selenka; *Halodeima coluber* (Semper)				x		x				x	
H. conica H. L. Clark							x					
H. cubana Ludwig				x								x
H. cumulus H. L. Clark					x		x					
H. curiosa Ludwig	*Holothuria fusco-cinerea* Jaeger				x		x				x	
H. curiosa var. *fuscorubra* Theel				x								
H. curiosa var. *philippinensis* Domantay	*H. fusco-cinerea* var. *philippinensis* Domantay				x							
H. curiosa var. *pervicax*	*H. fusco-cinerea* Jaeger; *H. fusco-cinerea* var. *pervicax*; *H. pervicax* (Selenka)				x						x	
H. dicorona Heding	*Halodeima dicorona* Heding				x							
H. dietrichii Ludwig					x							
H. difficilis Semper	*Actinopyga parvula* H. L. Clark; *Argiodia parvula* Pearson; *Mulleria parvula* Hamcke; *Actinopyga difficilis* Deichmann; *Holothuria (Microthele) difficilis* Panning; *H. frequentiamensis* H. L. Clark				x		x			x	x	x
H. edulis Lesson	*Trepang edulis* Lesson; *Holothuria signata* Ludwig				x	x	x			x	x	

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Holothuria erinaceus Semper					x		x				x	
H. flavo-maculata Semper	*Holothuria fusco-coerula* Theel						x			x		
H. fisheri Domantay				x								
H. fossor Deichmann				x			x				x	x
H. fusco-olivacea Fisher							x			x		
H. fusco-punctata Jaeger							x					
H. fusco-rubra Theel				x						x		
H. gelatinosa Heding										x		
H. glaberrima Selenka	*Holothuria lubrica* var. *glaberrima* Selenka; *H. erinaceus* Semper; *H. erinaceus* var. *pygmae* Semper			x	x		x				x	x
H. gracilis Semper					x		x					
H. graeffei Semper	*Holothuria (Bohadschia) graeffei* Semper				x		x				x	
H. gyrifer Selenka	*Stichopus gyrifer* Selenka; *Holothuria monacaria* Lesson; *H. patagonia; Stichopus (Holothuria) patagonicus* Perrier			x	x	x	x			x	x	x
H. hamata Pearson											x	
H. hawaiianensis Fisher										x		
H. hartmeyeri Erwe							x				x	
H. hjalmari Deichmann												
H. hypamma H. L. Clark							x					
H. humilis Selenka							x					

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Holothuria homoea H. L. Clark							x					
H. imitans Ludwig	*Holothuria surinamensis* H. L. Clark; *H. floridana* H. L. Clark			x			x			x	x	x
H. immobilis Semper					x		x			x	x	
H. impatiens (Forskal)	*Fistularia impatiens* Forskal; *Holothuria botellus* Selenka *H. aphanes* Lampert; *H. fulva* Q. & G.			x	x		x			x	x	x
H. impatiens var. *concolor* H. L. Clark				x								
H. impatiens var. *ludingae* Domantay				x								
H. inhabilis Selenka	*Holothuria hypamma* H. L. Clark			x			x					
H. inornata Semper				x								
H. insignis Ludwig	*Halodeima insignis* (Ludwig)				x							
H. integra Koehler & Vaney											x	
H. isuga Mitsukuri						x						
H. kurti Ludwig	*Holothuria lamperti* Sluiter				x		x				x	
H. kefersteinii (Selenka)	*Stichopus kefersteinii* Selenka			x								
H. languens Selenka	*Holothuria imitans* Theel			x								x
H. lentiginosa Marenzeller				x								
H. lentiginosa var. *clarionensis* Domantay				x								
H. leucospilota (Brandt)	*Stichopus (Gymnochirota) leucospilota* Brandt; *Holothuria vagabunda* Selenka			x	x	x	x			x	x	x

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Holothuria lubrica Selenka	*Mulleria lubrica* Sluiter; *Holothuria kapiolaniae* Bell; *H. (Microthele) lubrica* Panning			x	x		x			x	x	x
H. lubrica var. *moebii* Ludwig					x	x					x	
H. marenzelleri Ludwig	*Holothuria marenzelleri* var. *theeli* Deichmann			x	x		x				x	
H. marmorata (Jaeger)	*Bohadschia marmorata* Jaeger; *Sporadipus (Colpochirota) ualensis* Brandt; *Holothuria ualensis* Brandt				x		x			x	x	
H. martensii Semper	*Holothuria subverta* H. L. Clark				x		x				x	
H. macroperona H. L. Clark							x					
H. michaelseni Ludwig							x					
H. modesta Ludwig							x				x	
H. moebii Ludwig	*Holothuria lubrica* var. *moebii* Ludwig				x	x	x				x	
H. monacaria (Lesson)	*Holothuria (Psolus) monacaria* Lesson; *H. macleari* Bell; *H. decorata* var. *Marenzeller*; *H. flammea* Q. & G.; *H. fuscopuntata* Q. & G.; *H. fasciola* Q. & G.; *Stichopus gyrifer* Selenka			x	x	x	x			x	x	
H. mortenseni Domantay				x								
H. neozelanica Mortensen			x									

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Holothuria cataleda Ludwig	*Holothuria klunzingeri* Lampert						x					
H. olivacea Ludwig							x				x	
H. ocellata (Jaeger)	*Bohadschia ocellata* Jaeger						x				x	
H. [illegible] Sluiter							x				x	
H. papillata Bell											x	
H. papillata var. *galapagoensis* Domantay				x								
H. paradoxa (Selenka)					x		x			x	x	
H. [illegible] Deichmann				x								
H. pardalis Selenka	*Holothuria [illegible]* Ludwig; *H. lineata* Ludwig; *H. peregrina* Ludwig; *H. [illegible]* Selenka; *H. tubulosa* Selenka; *Halodeima pardalis* (Selenka)			x	x		x			x	x	
H. pardalis var. *cebuensis* Domantay					x							
H. [illegible] Lesson										x		
H. parva Lampert	*Holothuria lubrica* var. *parva* Mitsukuri; *Halodeima parva* (Lampert)										x	
H. pertinax Ludwig	*Halodeima pertinax* (Ludwig)									x		
H. [illegible] Selenka					x		x			x	x	
H. platei Ludwig									x			
H. princeps Selenka												x
H. prompta Koehler & Vaney											x	
H. pseudofossor Deichmann			x									

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Holothuria pulchella Selenka					x		x			x	x	x
H. pulla Selenka	*Microthele aethiops* Brandt; *Holothuria atra* Domantay 1933; *H. pulla* Panning				x		x			x	x	
H. remollescens Lampert							x					
H. rigida (Selenka)	*Stichopus rigidus* Selenka; *Cystipus pleuripus* Haacke;						x					
H. rugosa Ludwig	*Holothuria triremis* Sluiter				x		x			x	x	
H. saecularis Bell					x		x				x	
H. saccularis var. *forskali* Domantay					x							
H. samoana Ludwig										x		
H. sanctori delle Chiaje	*Holothuria farcimen* Selenka				x		x					
H. scabra Jaeger	*H. tigris* Selenka; *H. cadelli* Bell; *H. gallensis* Pearson; *Halodeima scabra* Jaeger				x	x	x			x	x	
H. sluiteri Ludwig										x		
H. spinifera Theel	*H. ocellata* H. L. Clark '38				x		x				x	
H. squamifera Semper					x		x			x		
H. subverta H. L. Clark							x					
H. surinamensis Ludwig				x								x
H. tenuissima Semper					x		x					
H. theeli Deichmann				x								
H. truncata Lampert							x					

Accepted Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Holothuria vagabunda Selenka	*Mesothuria* (*Gymnochirota*) *leucospilota* Brandt; *Halodeima vagabunda* (Selenka)											
H. cavicauda Deichmann	*Holothuria cinereola* Semper											
H. edulis Semper	*Bohadschia vitiensis* Pearson; *Holothuria tenuissima* Semper; *H. clemens* Ludwig; *H. sacra* Semper											
H. whitmaei Bell	*Mesothuria whitmaei* (Bell)											
H. acra Deichmann												
Labidodemas americanum Deichmann												
L. semperianum Selenka					x			x				
Thelenota anax (Jaeger)	*Trepang ananas* Jaeger; *Holothuria* (*Thelenota*) *ananas* Brandt; *Stichopus anax* Semper				x			x				
T. anax H. L. Clark								x				
Actinopyga echinites (Jaeger)	*Mulleria echinites* Jaeger; *Holothuria* (*Actinopyga*) *echinites* Panning				x			x		x		
A. echinites var. *bertini* Deichmann												
A. formosa (Selenka)	*Mulleria formosa* Selenka				x			x				
A. lecanora (Jaeger)	*Mulleria lecanora* Jaeger											
A. lubrica (Sluiter)	*M. lubrica* Sluiter; *Holothuria labrica* Selenka; *H. lubrica* var. *lubrica* Mitsukuri; *H. kapiolaniae* Bell						x	x		x		x

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Actinopyga mauritiana (Q. & G.)	*Holothuria mauritiana* Q. & G. *Mulleria mauritiana* Ludwig; *M. varians* Selenka				x		x			x	x	
A. miliaris (Q. & G.)	*Holothuria miliaris* Q. & G. *Mulleria miliaris* Brandt; *Holothuria lineolata* Q. & G.				x		x			x	x	
A. nobilis (Selenka)	*Argiodia maculata* (Brandt); *Mulleria nobilis* Selenka; *Holothuria maculata* Brandt			x	x		x			x	x	
A. nobilis var. *tigris* Domantay	*Argiodia maculata* var. *tigris* Domantay				x		x					
A. obesa (Selenka)	*Mulleria obesa* Selenka; *Holothuria (Actinopyga) obesa* (Selenka)				x		x			x	x	
A. parvula (Selenka)	*M. parvula* Selenka; *Holothuria parvula* (Selenka); *H. captiva* Ludwig; *H. abbreviata* Heilprin.			x	x		x			x	x	x
A. serratidens Pearson	*Holothuria (Actinopyga) serratidens* Pearson				x						x	
Microthele excellens (Ludwig)	*Mulleria excellens* Ludwig; *Argiodia excellens* Pearson									x		
Stichopus badionatus Selenka	*Stichopus haytiensis* Semper; *S. mobii* Semper; *S. errans* Ludwig; *S. maculatus* Greef; *S. assimilis* Bell; *S. diaboli* Heilprin; *S. badionatus* forma *diaboli*			x	x	x	x					x

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Stichopus californicus (Stimpson)	*Holothuria californicus* Stimpson; *Parastichopus californicus* (Stimpson)			x				x				
S. chloronotus Brandt	*Stichopus cylindricus* Haacke; *S. (Perideris) chloronotus* Brandt			x	x	x	x	x		x	x	
S. ellipes H. L. Clark							x					
S. fuscus Ludwig				x								
S. horrens Selenka	*S. godeffroyi* Semper; *S. godeffroyi* var. *pigmaeus* Semper; *S. tropicalis* Fisher				x		x			x	x	
S. japonicus Selenka	*Holothuria armata* Selenka; *Stichopus japonicus* var. *typicus* Theel; *S. armatus* Augustin; *S. roseus* Augustin				x	x		x		x	x	
S. ludwigii Erwe							x					
S. mollis (Hutton)	*H. mollis* Hutton; *Stichopus simulans* Dendy & Hindle; *Stichopus simultans* Erwe		x				x					
S. naso Semper					x		x				x	
S. paradoxus Lampert							x					
S. parvimensis H. L. Clark	*Parastichopus parvimensis* (H. L. Clark)			x				x				
S. sitchaensis Ludwig		x				x						
S. variegatus Semper				x	x	x	x			x	x	
S. variegatus var. *hermanni* Semper					x		x					

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Parastichopus johnsoni Theel				x				x				
P. nigripunctatus (Augustin)	*Stichopus depressus* Augustin					x						
DENDROCHIROTE HOLOTHURIOIDEA												
Acolochirus challengeri (Theel)							x					
Actinocucumis difficilis Bell							x					
A. longipedes H. L. Clark							x					
A. quinquangularis (Sluiter)	*Pseudocucumis quinquangularis* Sluiter						x					
A. typicus Ludwig							x					
A. peruviana (Lesson)	*Holothuria peruviana* Lesson; *Trepang peruviana* Jaeger; *Anaperus peruanus* Troschel; *Thyone peruana* Selenka			x					x			
Apentamera lepra Deichmann				x								
Apentacta spinosa Q. & G.							x					
Athyonidium chilensis (Semper)	*Thyone (Stolus) chilensis* Semper; *Eucyclus duplicatus* Lampert			x					x			
A. deichmannae Domantay				x								
Athyone glasselli (Deichmann)	*Thyone glasselli* Deichmann; *Thyone briareus* (Lesueur)			x								
Cucumaria adela H. L. Clark							x					
C. analis var. *sonorae* Domantay				x								
C. bicolor Bell							x					

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Cucumaria calcigera (Stimpson)	*Pentacta calcigera* Stimpson					x						x
C. calcigera var. *catalinensis* Domantay				x								
C. californica Semper				x		x		x				
C. canescens Semper					x							
C. citrea Semper					x							
C. chilensis Ludwig				x				x	x			
C. chronhjelmi Theel		x				x						
C. conjungens Semper					x							
C. crax Deichmann				x								
C. crax var. *dotae* Domantay				x								
C. crocea var. *croceoides* (Vaney)				x								
C. curata Cowles				x								
C. dubiosa Semper	*Cucumaria leonina* Ludwig			x					x			
C. elongata Duben & Koren				x								x
C. elongata var. *californica* Domantay				x								
C. godeffroyi Semper									x			
C. japonica Semper						x						
C. lamperti Ohshima						x						
C. lissoplaca H. L. Clark		x		x				x				
C. longipeda Semper					x							
C. lubrica H. L. Clark		x										
C. maculata Semper					x							

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Cen-
Cucumaria mirabilis Theel					x		x					
C. miniata (Brandt)	*Cladodactyla* (*Polyclados*) *miniata* Brandt; *Cucumaria albida* Selenka; *C. japonica* Lampert	x		x		x		x				
C. mosaica Kohler & Vaney						x						
C. piperata (Stimpson)	*Pentacta piperata* Stimpson	x		x				x				
C. populifera (Stimpson)	*Pentacta populifera* Stimpson	x		x				x				
C. pseudocurata Deichmann				x								
C. saxecola Brady & Robertson				x								
C. semperi Bell							x					
C. squamatoides H. L. Clark	*Cucumaria squamata* Joshua & Creed						x					
C. steineni Ludwig				x								
C. striata Joshua & Creed							x					
C. sykion (Lampert)	*Samperia sykion* Lampert; *Cucumaria sykion* Theel; *C. insolens* Theel; *C. leonina* var. *africana* Britten			x			x				x	x
C. trachyplaca H. L. Clark		x						x				
C. tricolor Sluiter					x							
C. vegae Theel		x						x				
C. versicolor Semper					x							
Discucumaria africana (Semper)	*Cucumaria africana* Semper; *Pseudocucumis theeli* Ludwig; *Ps. africana* Ludwig						x					

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Euthyonidium ovulum (Selenka)	*Stolus ovulum* Selenka; *Thyone ovulum* Deichmann			x					x			
E. veleronis Deichmann				x								
Eupentacta pseudoquinquesemita Deichmann								x				
E. pseudoquinquesemita var. *rosea* Domantay												
E. quinquesemita (Selenka)				x								
E. quinquesemita var. *cari* Domantay												
Echinocucumis adversaria Semper					x							
Taorsonia jeffreysi Herding											x	
Neothyone gibber (Selenka)	*Stolus gibber* Selenka; *Thyone gibber* Semper; *Th. cymalis* Ludwig			x					x			
N. gibbosa Deichmann				x					x			
N. panamensis (Ludwig)				x					x			
N. villadolidi Domantay				x								
N. saccllus (Selenka)				x								
Neopentamera averigua Deichmann				x								
Leptopentacta grisea H. L. Clark							x					
L. maccullochae Domantay				x								
L. nina Deichmann				x								
L. nova Deichmann				x								

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Leptopentacta nova var. *colombiana* Domantay				x								
L. panamica Deichmann				x								
Ocnus pygmaeus Semper				x								
O. imbricatus Semper				x								
Lipotrapeza dearmatus (Dendy & Hindle)	*Phyllophorus dearmatus* Dendy & Hindle;						x					
L. ventripes (Joshua & Creed)	*P. ventripes* Joshua & Creed						x					
L. vestiens (Joshua)	*P. vestiens* Joshua						x					
Mensamaria bicolumnata (Dendy & Hindle)	*Pseudocucumis bicolumnatus* Dendy & Hindle						x					
M. intercedens (Lampert)	*P. intercedens* Lampert; *P. eurystichus* H. L. Clark						x					
M. thomsoni (Hutton)	*Cucumaria thomsoni* Hutton; *C. mutans* Joshua; *Pseudocucumis thomsoni* Mortensen						x					
Pachythyone lugubris (Deichmann)	*Thyone lugubris* Deichmann			x								
P. pseudolugubris Deichmann				x								
P. rubra (H. L. Clark)	*Thyone rubra* H. L. Clark			x				x				
Pattalus mollis Selenka	*Pattalus mollis* Selenka; *Thyonidium peruanum* Semper; *T. molle* Semper; *Anaperus peruana* Verrill; *Pattalus peruana* Verrill; *Phyllophorus peruvianus* H. L. Clark								x			

SCIENTIFIC NAME	SYNONYM	NORTH PACIFIC	SOUTH PACIFIC	EAST PACIFIC	WEST PACIFIC	N.W. PACIFIC	S.W. PACIFIC	N.E. PACIFIC	S.E. PACIFIC	CENTRAL PACIFIC	INDIAN OCEAN	ATLANTIC OCEAN
Pentacta australis (Ludwig)	*Colochirus australis* Ludwig; *C. doliolum* Erwe						x					
P. bobustoides Ekman							x					
P. challengeri (Theel)	*Colochirus challengeri* Theel						x					
P. crassa Ekman	*Colochirus crassa* Ekman						x					
P. cucumis Semper	*C. cucumis* Semper						x					
P. dispar Lampert	*C. dispar* Lampert						x					
P. doliolum (Pallas)	*Actinia doliolum* Pallas; *Colochirus doliolum* v. Marenzeller; *Cucumaria discolor* Theel						x				x	x
P. jagorii (Semper)	*Colochirus jagorii* Semper						x					
P. minuta (Ludwig)	*C. minutus* Ludwig						x					
P. peruana (Semper)	*C. peruanus* Semper			x					x			
P. quadrangularis (Troschel)	*C. quadrangularis* Troschel; *C. coerulcus* Semper; *Holothuria quadrangularis* Lesson; *Pentacta coerulea* H. L. Clark						x					
P. tuberculosa Q. & G.	*Holothuria tuberculosa* Q. & G.; *Colochirus tuberculosus* Semper; *C. anceps* Semper; *Pentacta tuberculosus* H. L. Clark						x					
P. trimorpha H. L. Clark							x					
P. robusta Ostergren	*Colochirus robustus* Ostergren; *C. squamatus* Sluiter						x					

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Pentathyone mirabilis (Ludwig)	*Thyone mirabilis* Ludwig; *Cucumaria areolata* Ekman						x					
Orbithyone megapodia H. L. Clark							x					
Pentamera beebei Deichmann				x								
P. charlottae Deichmann		x		x				x				
P. chierchia (Ludwig)				x					x			
P. chiloensis (Ludwig)	*Cucumaria chiloensis* Ludwig; *C. tabulifera* R. Perrier			x				x	x			
P. panamensis (Verrill)	*Ocnus panamensis* Verrill			x								
P. pseudocalcigera Deichmann				x				x				
P. pseudopopulifera Deichmann				x				x				
P. zacae Deichmann				x								
Pseudocolochirus axiologus H. L. Clark	*Colochirus axiologus* H. L. Clark						x					
Pseudocucumis aciculus (Semper)	*Cucumaria acicula* Semper; *Pseudocucumis acicula* Ludwig				x		x					
P. africanus (Semper)	*Cucumaria africana* Semper; *Pseudocucumis theeli* Ludwig					x	x				x	
P. eurystichus H. L. Clark							x					
P. roxasi Domantay					x							
Psolicucumis apneumona Heding	*Cucumaria nocturna* Sluiter										x	
Phyllophorus aculeatus Ludwig				x								
P. brocki Ludwig							x					

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Phyliophorus cebuensis (Semper)	*Thyonidium cebuense* Semper				x		x					
P. cornus Heding					x							
P. holothurioides Ludwig							x					
P. magnus Ludwig					x							
P. panningi Domantay				x								
P. parvipedes H. L. Clark							x					
P. perspicillum Selenka					x							
P. proteus Bell							x					
P. schmeltzii (Ludwig)	*Thyonidium schmeltzii* Ludwig						x					
P. thyonoides H. L. Clark							x					
P. trapezus H. L. Clark							x					
P. zacae Deichmann				x								
Psolus ostertieus Philippi				x	x							x
Ps. boholensis Semper					x							
Ps. boholensis pandanensis Semper					x							
Ps. buchannani Domantay		x		x				x				
Ps. chitonoides H. L. Clark					x							
Ps. complanatus Semper				x								
Ps. diomedae Ludwig						x						
Ps. japonicus Ostergren							x					
Ps. minutus H. L. Clark									x			
Ps. patagonicus Ekman												

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Psolus pourtalesi Theel				x								
Ps. spinuliferus H. L. Clark							x					
Ps. squamatus var. *segregatus* Perrier	*Psolus squamatus* H. L. Clark; *Ps. pauper* Ludwig	x						x	x			
Ps. valvatus Ostergren				x								
Psolidium convergens R. Perrier	*Cucumaria convergens* Joshua						x					
Ps. dorsipes Ludwig				x					x			
Ps. dorsipes var. *gadieli* Domantay				x								
Ps. ekmani Deichmann				x								
Ps. cubullatum Deichmann				x								
Ps. granuliferum H. L. Clark				x			x					
Ps. nigrescens H. L. Clark							x					
Ps. planum Deichmann				x					x			
Thyone alba H. L. Clark	*Thyone dura* Koehler & Vaney						x					
Th. axiologa H. L. Clark							x					
Th. belli Ludwig				x								
Th. benti Deichmann				x				x				
Th. benti var. *zacae* Deichmann				x								
Th. bidentata Deichmann				x								
Th. buccalis Stimpson	*Stolus sacellus* Selenka; *Thyone rigida* Semper; *Stereoderma murrayi* Bell; *Thyone sacellus* Erwe						x					
Th. ceciliae Domantay				x								
Th. colnettensis Domantay				x								

Current Name	Synonymy	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
[illegible] Valeyi											x	
	Stolus gibber Selenka, [illegible] Lampert			x								
[illegible]	[illegible] Lampert						x					
[illegible]				x								
Th. grisea H. L. Clark							x					
Th. inermis var. *coronensis* [illegible]				x								
Th. leckeri [illegible]				x								
Th. lugubris Deichmann				x								
Th. micra H. L. Clark							x					
Th. minuta H. L. Clark							x					
Th. mirabilis [illegible]							x					
Th. neofusus Deichmann				x								
Th. nigra Joshua & Creed							x					
Th. okani Bell							x					
Th. paratrocha Deichmann				x								
Th. papuensis (Theel)	*Thyone fusca* var. *papuensis* Theel; *Thyone cantanea* Lampert						x					
Th. perforata H. L. Clark							x					
Th. perissa H. L. Clark							x					
Th. sacellus (Selenka)	*Stolus sacellus* Selenka						x				x	
Th. sketchi Lampert							x					
Th. stygia Semper					x							

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Thyone strangeri Deichmann				x								
Th. turricata var. *lourdesae* Domantay				x								
Th. unisemita (Stimpson)				x								
Th. villosa Semper					x							
Thyonacta mexicana Deichmann				x								
Thyonepsolus beebei Deichmann				x								
Th. hancocki Deichmann				x								
Th. nutriens H. L. Clark	*Psolidium nutriens* Ludwig			x				x				
Th. veleronis Deichmann				x								
Thyonidium alexandri Fisher										x		
Th. cebuense Semper					x							
Th. hawaiianse Fisher										x		
Staurothyone distincta H. L. Clark							x					
S. inconspicua (Bell)	*Cucumaria inconspicua* Bell						x					
S. vercoi (Joshua & Creed)	*Thyone vercoi* Joshua & Creed						x					
Stelinus cataphractus Selenka	*Psolus (Hyposolus) ambulator* Bell; *Theelia ambulatrix* Erwe						x					
Urodemas hamatum Sluiter	*Phyllophorus hamatus* Sluiter						x					
U. perspicillum Selenka							x					
U. schmeltzii (Ludwig)	*Thyonidium schmeltzii* Ludwig						x					
Colochirus anceps Selenka					x							

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
[illegible]					x							
C. crassa var. *dyscritus* Hedling					x							
C. eucnemis Semper					x							
[illegible]					x							
C. lopezi Hedling											x	
C. quadrangularis Lesson					x							
C. tuberculosus Q. & G.					x							
[illegible]					x							
[illegible]					x							
H. molpadioides pallucida Heding					x							

APODAL HOLOTHUROIDEA

Apheledactyla trania Heding											x	
Molpadia altimensis H. L. Clark												
M. antartica (Theel)	*Trochostoma antarticum* Theel					z	z					
M. arenicola (Stimpson)			x			x						
M. dimilis H. L. Clark				x								
M. intermedia (Ludwig)							x					
M. musculus Risso				x								
				x								
M. productamensis H. L. Clark								x				

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Acaudina delicata H. L. Clark	*Aphelodactyla delicata* H. L. Clark						x					
A. leucoprocta H. L. Clark	*Aphelodactyla leucoprocta* H. L. Clark						x					
Paracaudina australis Semper	*Molpadia australis* Semper; *Pseudocaudina australis* Heding						x					
P. chilensis (J. Muller)	*Molpadia chilensis* Muller; *Caudina chilensis* (J. Muller)		x	x	x	x	x	x	x			
P. chilensis var. *ransonnetii*	*Caudina ransonnetii* v. Marenzeller; *C. chilensis* J. Muller; *Pseudocaudina ransonnetii* Heding *Paracaudina ransonnetti* Heding			x		x	x	x	x			
P. clarki Domantay				x								
P. tetrapora H. L. Clark	*Caudina tetrapora* H. L. Clark						x					
Ceraplectana buchannani Domantay				x								
Gephyrothuria alcocki Koehler & Vaney				x								
G. velerosa Domantay				x								

SYNAPTIDAE

SCIENTIFIC NAME	SYNONYM	NORTH PACIFIC	SOUTH PACIFIC	EAST PACIFIC	WEST PACIFIC	N.W. PACIFIC	S.W. PACIFIC	N.E. PACIFIC	S.E. PACIFIC	CENTRAL PACIFIC	INDIAN OCEAN	ATLANTIC OCEAN
Euapta godeffroyi (Semper)	*Synapta godeffroyi* Semper			x	x		x			x	x	x
Opheodesoma australiensis Heding	*Ophcodesoma ramispicula* Heding				x		x					
O. africana Heding											x	
O. glabra (Semper)	*Synapta glabra* Semper				x		x			x		
O. grisea (Semper)	*Synapta grisea* Semper				x		x			x	x	
O. spectcbilis Fisher				x	x					x	x	
O. spectabilis var. *puerto-galerae* Domantay					x							
Chondrocloca indivisa (Semper)	*Synapta indivisa* Semper				x		x					
C. macra H. L. Clark							x					
C. nigra (Semper)	*Synapta nigra* Semper; *Synaptula nigra* H. L. Clark				x		x					
C. recta (Semper)	*Synapta recta* Semper				x		x					
Anapta amurensis Britten						x						
A. gracilis (Semper)	*Synapta gracilis* Semper				x					x		
A. fallax Lampert										x		
A. inermis Fisher												
A. ludwigi Britten										x		
A. subtilis Sluiter						x						
Leptosynapta dolabrifera (Stimpson)	*Synapta dolabrifera* Stimpson; *Leptosynapta variopatina* Heding; *L. jaksonia* Heding			x			x			x		

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Leptosynapta circopatina H. L. Clark				x								x
L. dyscrita H. L. Clark							x					
L. ictinodes H. L. Clark							x			x		
L. inhaerens (O. F. Muller)	*Holothuria inhaerens* O. F. Muller	x		x		x		x				x
L. latipatina H. L. Clark				x			x					
L. ooplax (v. Marenzeller)	*Synapta ooplax* v. Marenzeller					x	x			x		x
Leptosynapta parvipatina H. L. Clark							x					
Labidoplax dubia (Semper)	*Synapta dubia* Semper					x				x		
Protankyra aculeata (Theel)	*Synapta aculeata* Theel					x						
P. autopista (v. Marenzeller)	*Synapta autopista* v. Marenzeller					x						
P. albatrosi Fisher						x						
P. bidentata (Woodward & Barrett)	*Synapta bidentata* Woodward & Barrett					x						
P. bisperforata H. L. Clark							x					
P. insolens (Theel)	*Synapta insolens* Theel						x					
P. kagoshimensis Ohshima						x						
P. magnihamulae Heding											x	
P. similis (Semper)	*Synapta similis* Semper				x		x			x		
P. verrilli (Theel)	*Synapta verrilli* Theel						x					
Polyplectana kefersteinii (Selenka)	*Synapta kefersteinii* Selenka			x	x		x			x		x
P. samoae Heding										x		
P. unispicula Heding										x		

Species Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Synapta beselii (Theel)					x							
S. dubia Semper					x							
S. innominata Ludwig					x							
S. maculata (Ch. & Eys.)	*Holothuria maculata* Ch. & Eys.			x	x	x	x			x	x	
S. maculata var. *andreae* Heding											x	
S. modesta Semper					x							
S. oceanica (Lesson)	*Holothuria oceanica* Lesson; *Synapta oceanica* Jaeger; *S. maculata* Clark 1908									x	x	
S. pseudo-digitata Semper	*Protankyra pseudo-digitata* (Semper)				x						x	
S. reticulata Semper					x							
Synaptula nigra (Semper)	*Synapta nigra* Semper				x		x			x		
S. mortenseni Heding										x	x	
S. recta (Semper)	*Synapta recta* Semper				x		x			x		
S. tualensis Heding					x							
S. psara Sluiter							x			x		
Patinapta crosslandii Heding										x	x	
CHIRIDOTIDAE												
Chiridota albatrossii Edwards						x						
Ch. dubia Semper					x							
Ch. discolor Eschscholtz	*Liosoma sitchaense* Brandt					x						
Ch. gigas Dendy & Hindle							x					

Scientific Name	Synonym	North Pacific	South Pacific	East Pacific	West Pacific	N.W. Pacific	S.W. Pacific	N.E. Pacific	S.E. Pacific	Central Pacific	Indian Ocean	Atlantic Ocean
Chiridota hawaiiensis Fisher										x		
Ch. incongrua Semper					x							
Ch. ingens Joshua							x					
Ch. magna H. L. Clark							x					
Ch. regalis H. L. Clark						x						
Ch. rigida Semper				x	x		x			x	x	
Ch. panaensis Semper					x							
Ch. uniserialis Fisher						x						
Ch. uniserialis var. *elementensis* Domantay				x								
Ch. variabilis Semper					x							
Ch. violacea John Muller				x								
Polycheira rufescens (Brandt)	*Chiridota rufescens* Brandt				x	x	x			x	x	
Taeniogyrus australianus (Stimpson)	*Chiridota australiana* Stimpson				x		x					
T. cidaridis Ohshima						x	x					
T. heterosigmus Heding							x					
Trochodota allani Joshua	*Taeniogyrus allani* Joshua						x					
T. maculata H. L. Clark							x					
T. roebuckii Joshua							x					
T. rosea Ohshima						x						
Scoliodota japonica (v. Marenzeller)	*Chiridota japonica* v. Marenzeller					x						
Scoliorhapis theeli Heding	*Scoliodota theeli* Heding						x					
Toxadora pacifica Ohshima				x		x						

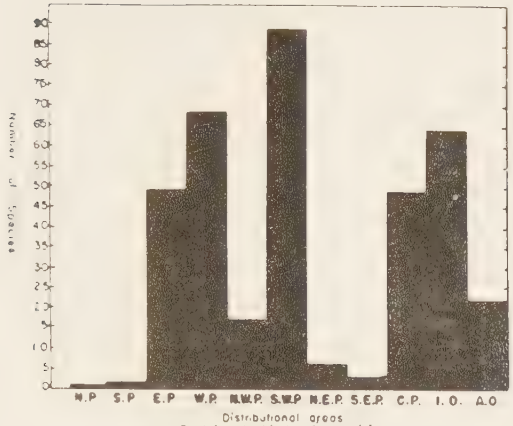

Fig. 1-Aspidochirote Holothurioidea

Fig 2-Dendrochirote Holothurioidea

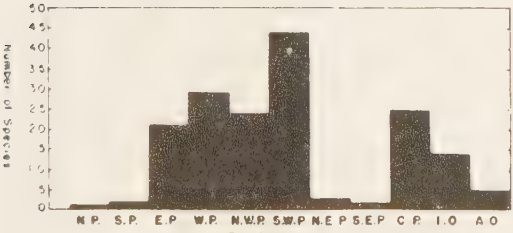

Fig. 3- Apodous Holothurioidea

Zoogeographical Distribution of the Indo-Pacific Littoral Holothurioidea

Legend

N.P. = North Pacific
S.P. = South Pacific
E.P. = East Pacific
W.P. = West Pacific
N.W.P.=Northwest Pacific
S.W.P.=Southwest Pacific
N.E.P.=Northeast Pacific
S.E.P=Southeast Pacific
C.P. = Central Pacific
I.O. = Indian Ocean
A.O.= Atlantic Ocean.

● Species recorded from both Atlantic and Indo-Pacific Oceans

DISTRIBUTION OF MARINE FISHES IN SOUTH EAST ASIAN WATERS

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The tropical marine fishfauna of South East Asian seas has in general a range from the East coast of Africa and the Red Sea in the West to far in the Pacific in the East, whereby the fishfauna as a whole gets poorer in species the farther away we are from the mainland of Asia.

This fauna does not reach the West coast of tropical America. It is essentially an Asian fishfauna.

There are circumtropic genera and even a few circumtropic species, but the greater part of this fauna is restricted to these waters.

Within this area several subareas can be distinguished.

The pattern is a very complex one, regulated by several coordinating and correlating or sometimes contrasting factors into which we still have not sufficient insight. Often it is stated in a handbook that a certain species of fish is found from India to Australia, but this does not always mean that it is found everywhere in the area mentioned. The occurrence may be continuous but also it may be that the species is found only in isolated patches of water of greater or lesser extent. As a rule we can take it that fishes as well as land animals are all adapted to their specific biotope. Many species are specialised in their food, they are more or less adapted to a certain salinity, to the kind of bottom and to other circumstances unknown thus far. Penetration of light may be a factor too, either directly or indirectly. In this latter case it is the food which is influenced directly by light.

Copepods sink deeper in clear water at daytime and fishes living on these copepods must follow them. So it happens that *Decapterus* species in the eastern part of the Java Sea where we have clear water, are living in deeper water than in the western Java Sea where the water is less clear. There the schools of *Decapterus* are found in the upper layers, sometimes even breaking surface. I know regions where *Decapterus* is living so deep that they are out of reach for the fishermen.

Thus one has to be careful when stating that a certain species is absent or at any rate rare in a given area. Whereupon depends our knowledge of the occurrence of a given species? The answer is just

this, in the majority of cases: "On the catches of the fisherman." And it is a well-known fact, that almost any kind of fishing method is more or less selective. By introducing a new kind of gear or even an alteration in size of a certain gear type or fishing in virgin water, we may have surprising results. Fish rare or unknown thus far appears now in great quantities on the fish-market. We have had at Djakarta a very good example as such in the sudden appearance of boat loads of *Parastromateus niger,* the Black Pomfret, whereas formerly this species was very rare. Not more than two or three specimens a week perhaps were seen before that time.

As far as our knowledge goes, we can divide the South East Asian seas into the following regions:

1. Coastal waters;
2. Shallow seas on shelf;
3. Oceanic waters;
4. Coral-reef waters.

Coastal waters can be divided into smaller units. We can divide them of course in waters bordering a sandy, muddy or rocky coast. These coast-forms have its influence on the fishes specially adapted to the shores, like *Blennius, Salarias, Periophthalmus* and others. But these faunas are of less importance for a general review as they are so strictly bound to their environment that several different communities may be found along a stretch of a few hundred meters.

More of importance are the midwater species. They are less bound to the formation of the shore as such. Generally, they are bound in a minor degree to the formation of the bottom. There are species however, being true midwater forms, which seem to prefer a muddy bottom like *Sardinella* species. Others like *Caranx crumenopthalmus,* for instance, like to swim above a sandy bottom. This is not a hard-and-fast rule of course, but in general it is what the fishermen reckon with when they go out for these species. At least this is so in Indonesian waters.

The composition of the seawater itself is of more importance to the midwater-fauna. Wherever there is a mixing with river water there is a special fishfauna which I shall call an aestuarine fishfauna. This fauna is living under aestuarine conditions in some cases tens of miles from land. According to my definition, aestuarine waters are therefore not especially found in an aestuary as such, but are also to be met much farther away. Guide species are, for instance, *Setipinna, Coilia,* some *Polynemids, Kurtus indicus, Harpodon nehereus, Trypauchen, Gobioides* and others. These species may be found in an aestuary proper like in some Sumatra aestuaries, but near rivers which have no aestuary and where tidal influence is small, these species are found in the rivermouth

proper and upstreams only to a very limited extent; whereas, they too occur far out at sea. The existence of this fauna is probably conditioned in the first place by a lowered salinity, though one should not think in too low percentages. A salinity of about 30 ‰ is probably the upper limit, almost true seawater therefore. Further the amount of silt seems to have an influence. At least according to my experience the muddier the river water is, the farther the aestuarine conditions reach. There is a coordination between the somewhat lowered salinity and the amount of silt resulting maybe in a high fertility of the water as shown by a rich diatom plankton. Such aestuarine fauna we find in front of the Indus and on the other side of the Indian Peninsula in front of the Ganges and Brahmaputra mouths. From there eastwards, there is a gap where the Burmese mountains reach the coast. Again such an area appears before the Salween and Irawaddy. The narrow part of the Straits of Malacca may be considered as one large aestuary. An aestuarine fauna fringes the whole coast of Borneo and the whole East coast of Sumatra. Farther North on the Asian mainland, we find isolated stretches of aestuarine waters of a great extent in the Gulf of Thailand and in front of the Mekhong and the big Chinese rivers. This aestuarine fauna is petering out to the North as far as the Yellow Sea.

Subject to this, it is to be noted that on the South coast of Java we have a rather large aestuary where the aestuarine fauna as such is lacking except *Gobioides* and *Eleutheronema tetradactylus*. It seems that elements of this fauna have not been able to cross the coastal stretches of the Indian Ocean from East Sumatra. The more remarkable is it, therefore, that on the south coast of New Guinea, where a system of big rivers empty into the sea, a similar aestuarine fishfauna appears again, partly composed of the same species like *Eleutheronema tetradactylus* and *Setipinna*, partly, composed of other new local species. A great field of investigation is still waiting for the ichthyologist. This isolated aestuarine fauna of New Guinea is separated by hundreds of miles of open deep sea from Borneo, the nearest coast where aestuarine conditions are found. Here a local aestuarine fauna, partly composed of other elements like another *Herpodon* species as on the Asian mainland, has come into being.

Stretches of coast along the open ocean often show no coastal zone in the water. The open sea, the oceanic conditions, come up to the shore itself. Thus it is possible that tuna's and related forms are caught there in traps, a few meters out from land, whereas these fishes are true open sea forms often even avoiding narrow channels between islands.

Seas on continental shelves are often influenced by the nearby land. Here, as for instance, in the Java Sea we may distinguish between a narrow stretch along the coast and the waters farther away. It is in-

teresting to observe that in a stretch, often not more than a few miles wide, species occur which are replaced farther out at sea by related forms. *Stolephorus zollingeri* and *heterolobus* are the more neritic, whereas *Stolephorus commersoni* is the more open sea form. *Rastrelliger neglectus* is the coastal, *R. kanagurta* the replacing open sea species, *Scomberomorus guttatus* the coastal, *Sc. commersoni* the more remote form. To these examples may be added various other ones like *Sardinella fimbriata* and *Sardinella perforata.*

A narrow or wider shelf is developed along the whole continent of Asia, but it reaches its greatest extension in the East in the so-called Sunda shelf covered by the Java Sea and part of the South China Sea, and in the East in the Sahul shelf covered by the Arafura Sea. Though these seas are very far apart their fishfauna is the same.

Fishes of true oceanic waters generally avoid the shelf-seas, e.g. tuna, some flying fishes, some sharks, which seldom venture far over the hundred fathom line, though they are not afraid of the vicinity of the coast, provided that this coast is bordered by deep water. Only the dwarf bonito and the dwarf tuna, *Euthynnus alletteratus* and *Thunnus tonggol* respectively, come into the shelf seas regularly.

Fishes of the coral reefs have a very restricted habitat. Many of them pass their whole life on one and the same reef and mingling of the total stock happens probably only by way of planktonic eggs and larvae. Others like parrot-fishes and probably species of *Caesio* seem to spawn in open water, miles away, whereafter they return to the reefs. Whether this is always the same one is still an open question.

So we can divide the South East Asian waters into the following four divisions, judging from an ecological point of view:

1. Coastal waters.

A broader or narrower band of water along the shores, influenced by steepness or configuration of the bottom, direction and strengths of currents, contamination by river water, windstrength and maybe other factors.

2. Shallow seas on a shelf.

Shelf waters coincide with the coastal waters wherever the shelf is narrow. In places where the shelf seas cover a wide area, they can have their own fauna.

3. Oceanic waters.

These waters cover the greater part of our area and may extend to the shore in places where we have a clear steep rocky coast and no rivers.

4. Coral-reef waters.

Coral-reef waters are very limited in extent. They are above the coral reefs.

AN ANALYSIS OF THE PELAGIC BIRD FAUNAS OF THE INDO-PACIFIC OCEANS

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I. Introduction

An analysis of the pelagic sea-bird faunas of any one of the three great oceans—the Atlantic, the Pacific and the Indian—cannot be dissociated from similar studies of the other two, and so though this essay is primarily concerned with the Indo-Pacific basins, the bird fauna of the Atlantic is constantly referred to. The method of inquiry pursued is that of a study of *faunas* and not *faunal regions*, and so necessitates a consideration of distribution patterns in the neighboring oceans.

This paper is a re-statement and an interpretation of known taxonomic and zoo-geographical facts and depends on the fulness and accuracy of these basic data. Where they were scanty or lacking, the author has made some bold speculations which may or may not be upheld by later investigation.

At this stage of knowledge of the subject, it seems debatable whether one is justified in giving more than a sketchy outline of the events which may have taken place. More detailed treatment of a subject, in which lack of adequate data forbids much precision, is bound to arouse unfortunate reactions. Workers outside of our particular field are not slow to point out the unsatisfying nature of such hypotheses, when they race too far ahead of the basic factual studies on which they depend. Thus in a review of a work on the fauna of Britain, T.T. Macan (1953, p. 172) likens the various components of faunas mixed up by the retreats and advances of the Ice Age as "an omelette, attempts to unscramble which are a source of continual fascination today. To a ringside observer, such as the reviewer, . . . the number of unknown factors seems to justify a sceptical attitude towards all attempts at unscrambling." Ultra-caution such as this might deter investigators from attempting to unscramble any type of biological omelette, and I am making bold to attempt something of the sort for a kindred problem in the Indo-Pacific. The unscrambling attempt is offered as a tentative proposal to other unscramblers for their comments and assistance.

The preparation of the paper has more than ever impressed on the author the indebtedness of all students of pelagic birds to the work

of Dr. Robert Cushman Murphy. It is an inspiration to others to reintensify the ornithological exploration of other islands in the Indo-Pacific and the collection of birds at sea to build up our store of facts on the nesting and the foraging ranges of the pelagic birds. During the course of the work, S. Ekman's "Zoogeography of the Sea," the revised English translation of his stimulating synthesis, "Tiergeographie des Meeres," was published, and it also has been laid under contribution.

II. Factors in the Problem

Though the three major oceans, the Pacific, Indian and Atlantic, contain many faunal elements in common, the Pacific is notable for the following characteristics: 1. A rich development of petrel forms unsurpassed by either the Indian or Atlantic Oceans, and approaching that of the Southern Ocean in number of species and races. 2. A strong development of terns. 3. An entire lack of gulls in the island archipelagoes, they being confined to the peripheral fringes.

Environmentally a significant characteristic of the Pacific Ocean, as compared with the others, from the standpoint of sea-bird colonisation, is the wealth of islands over a large part of its area and in most of its hydrologic zones, as compared with the more peripheral distribution of islands in the main basins of the Indian and Atlantic Oceans. In this respect much of the Pacific Ocean resembles the circumpolar Southern Ocean. The eastern portion of the Pacific, however, is singularly lacking in islands, this abyssal region constituting an important barrier in the continuity of faunas which depend on shallow shelves and banks, and Ekman (1953, p. 73) considers it as causing "the most pronounced break in the circumtropical warm-water fauna of the shelf." The main effect on the pelagic sea-birds has been the deprivation of nesting sites in this area, and the geographical isolation thus contributed to has permitted some subspeciation to have gone on.

During the Tertiary and Pleistocene one hydrological barrier in particular and three physical or geographical barriers have been of paramount importance in controlling the spreads and dispersals of pelagic sea-birds within and between the three major oceans. They have served as lock-gates, as it were, in regulating the ebb and flow of species' movements. They are:

1. The barrier of tropical, equatorial, waters was breached repeatedly during the Pleistocene glaciations, enabling the transgression through them of northern and southern elements, giving rise to the phenomenon of anti-tropicality or bipolarity (for a modern discussion see Hubbs, 1952, p. 324). Ekman (1953, p. 257) postulates such penetrations during the greater part of the Tertiary, and indeed pre-Glacial

transgressions are demanded for some of the hypothetical species-histories in the present paper.

2. The availability of the following four water gaps:
   (a) The Panama gap between North and South America, enabling a passage between the Pacific and Atlantic Oceans in the equatorial zone. This has been mapped, from various geological authorities, by Mayr (1946, Fig. 1), who states that it was functional from the lower Eocene to the upper Pliocene.
   (b) The Bering water gap establishing a passage between the same two oceans in the northern cool water zone. This gap would tend to be closed during glacial periods and open in the warm inter-glacial intervals, through eustatic lowering and raising of sea-level. Thus its existence would be associated with all the conditions favouring free movement between the seabirds of the North Atlantic and North Pacific.
   (c) The Indo-Malayan water gap between the Indian and Pacific Oceans in the equatorial zone.
   (d) The Mediterranean-Indian Ocean Gap served as a means of communication between the two basins until the late Tertiary period.

Several periods of major global cooling occurred during the Pleistocene Ice Ages, thus providing the opportunity—even if not all succeeded—for repeated transgressions of cool-water species across the equatorial belt. The first to propound this explanation for the so-called "bipolar" distribution of marine fauna was Charles Darwin. Regan (1916, p. 16), though without specifically mentioning the Ice Ages, postulated a past cooling of the tropical waters to explain the present distribution of the pilchards (*Sardina*). L. S. Berg (1933) fully elaborated the thesis in respect to Ice Age coolings and K. H. Voous (1949) invoked it for his theory of the evolution of *Fulmarus glacialis* from the Antarctic *F. glacialoides*. Hubb's review (1952, but originally put forward in 1949) re-states and extends the general thesis, which appears essential for a rational explanation of sea-bird relations to the major ocean basins.

Ekman (1953, p. 244 *et seq.*, in a most useful summary of the "bipolarity" problem) advances cogent arguments for these processes having taken place even prior to the period of the Pleistocene Ice Ages, namely during the greater part of the Tertiary. He states (p. 257): "During the Tertiary Period we cannot assume glacial periods as a cause, but perhaps geographical changes influenced the course of the

cold ocean currents or there may have been other causes. And the more millions of years have been available for development, the greater is the chance for exceptional and favourable combinations of factors to occur; this may possibly also have played its part."

It would appear (as will be seen later from the distribution of the skuas, Pacific albatrosses, the fulmars, and the petrels of the Cape Verde and Madeira group of islands) that the main highway for these faunal transgressions was alongside the *western* coasts of the adjacent continents, in other words in the eastern Pacific and in the eastern Atlantic (cf. Murphy and Penneyer, 1952, p. 35). Ekman (1953, p. 248) presents similar arguments for the invertebrate and fish faunas of the shelf, stating that "of the two main longitudinal routes for the benthal fauna, the West African and the West American, the latter is by far the more important." The surface temperature charts provided by Schott (1926, 1935) demonstrate the latitudinal narrowness, even at the present time, of the warm-water tropical belt in the eastern Atlantic and the eastern Pacific.

No evidence of a transgression exists in the Indian Ocean; if it occurred no southern elements could have survived in the absence of cool-water refuges in the geographically limited northern Indian Ocean (cf. also Ekman, *ibid.* p. 72, who believes that no climatic change of importance took place in the Indo-Malayan region either in the Tertiary or Quaternary Periods and "the tropical fauna of the Cretaceous and Eocene could maintain itself in all its tropical abundance and developed until our own time.")

The possible existence of other, mid-oceanic, routes for the passage of the cool-water faunas across the tropics in Glacial Periods and in the later Tertiary is suggested by the occurrence of islands in the equatorial Pacific and Indian Oceans with immense stores of ancient guanos accumulated in the Pleistocene, and quite unassociated at the present time with any bird colonies capable of producing them. Hutchinson (1950) has done a lasting service in marshalling all known facts on the subject. He assumes considerable climatic and hydrological changes in the central Pacific to account for the accumulation of these deposits, the like of which is now known only from the Humboldt Current region of South America. As C. A. Fleming has pointed out to me (*in litt.*) these equatorial guano islands may be significant as pointers to the existence of flourishing bird haunts in the Pleistocene, when the equatorial upwelling divergence belts were more intensive than they are now. As Hutchinson has shown for the Peru and Chile coasts such areas are very sensitive to changes in world climate and the post-Pleistocene period has seen radically altered conditions in the equatorial Pacific and Indian Oceans. This subject will provide re-

warding results if further studied conjointly by the ornithologist and oceanographer, but it is clear from Hutchinson's treatise that more data are required.

As has been mentioned when dealing with the Bering gap, the Pleistocene Ice Ages would affect the magnitudes of the various water gaps. The Indo-Malayan gap, with its considerable areas of shallow shelves, would have been most affected by the eustatic rise and lowering of sea-level; Mayr has stated (1944, p. 113) that during the height of the last glaciation the width of the Timor Strait, now more than 300 miles, was reduced to 45–75 miles. The waterways were never completely closed, however, during the Pleistocene and the Australian and Asiatic land masses have been separated since the early Eocene. Nevertheless, this area of shallow seas and innumerable barrier islands, would to some extent impede pelagic sea-birds and is still unoccupied by some species common in the oceans on either side.

The water gaps in the Panama zone ceased to exist by the time of the Pleistocene glaciations. Hence species which made passages through them, and which had earlier in their history made trans-equatorial transgressions, must have made such tropical crossings before the Ice Ages.

III. Faunal Elements in the Indo-Pacific Oceans

1. Introduction.

From the standpoint of their proximate origins, the pelagic sea-birds may be divided into three categories: 1, a Northern, or Boreal, group; 2, a Pan-Tropical group, and, 3, a Southern group (cf. Mayr, 1946, p. 13; Ekman, 1953, pp. 186, 329, has an essentially similar primary division of the invertebrate and fish faunas).

I am not concerned here with the ultimate origin of particular groups, but of the more immediate relationships of species and genera. Thus, though all petrels might be considered, from the standpoint of ultimate origins, to be ranked as part of a southern fauna, the existing species of some groups, such as the storm-petrels of the genus *Oceanodroma* and the *Puffinus puffinus* complex, have certainly undergone secondary differentiation in the northern temperate regions, and are considered in this review as northern elements. Similarly the group of races of *Puffinus lherminieri,* though they are clearly derived from a southern ancestor (*P. assimilis*) have undergone a cycle of secondary evolution in the tropical seas of two oceans and may conveniently be considered as members of the pan-tropical fauna. Ekman (1953, p. 200, footnote) was faced with a similar problem in dealing with the marine invertebrates and fishes.

The main categories should be divided into primary and secondary elements, where they can be clearly recognised as such. In this paper I have attempted this only for the Pan-Tropical Fauna. In the cases of the other two faunas the ranking of most of the species or species groups is evident from the context.

The principal pelagic bird faunas in the Indo-Pacific region may, accordingly, be classified into the following categories on the basis of distributional and probable evolutionary patterns:

2. SOUTHERN ELEMENTS.

Ekman (1953, p. 229) holds that the antarctic shelf has been a centre of development for marine animals for a long period of time: "a cold climate has continued without disturbance from the transition between the Cretaceous and the Tertiary Periods into recent times," thus accounting for its richness of species. Proceeding northwards from the antarctic various faunal sub-divisions are recognisable to the sub-tropics and Ekman, on the basis mainly of invertebrate studies, recognises the following: Antarctic, Antiboreal (cold temperate), and Warm Temperate.

Murphy (1936, p. 71) has shown how different species of pelagic sea-birds characterise the different hydrological zones of surface water. His work has demonstrated how various elements of the southern fauna have adapted themselves to varying degrees of coldness, and one can conveniently speak of the birds of the Antarctic Zone, those of the Sub-Antarctic Zone and those of the Sub-Tropical Zone. Some are not so restricted but in several cases the convergences between these water masses represent real boundaries between breeding ranges. Closely allied species and sub-species are representative of different zones.

PENGUINS

No Penguin has penetrated into the temperate waters of the Northern Hemisphere, but *Spheniscus mendiculus* of the Galapagos region, has reached the Equator as a breeding species and actually ranges north of it.

ALBATROSSES

These birds are another highly characteristic southern group. The few species in the North Pacific are the descendants of trans-equatorial colonists and will be considered as secondary elements of the Tropical Fauna.

PETRELS

Fulmarus glacialis and F. glacialoides

The northern Fulmar breeds in the Pacific in the Kurile Islands, Bering Sea and Aleutian Islands, and in the Atlantic in Baffin Land,

Greenland, Spitzbergen and northern Europe. The closely related southern Fulmar, *F. glacialoides,* nests wholly within the Antarctic Convergence, but migrates to beyond the Sub-tropical Convergence, particularly in the Atlantic Ocean and the eastern Pacific.

Voous (1949) has shown that *glacialoides* resembles more the north Pacific race (*rodgersi*) than the north Atlantic faces of the *F. glacialis,* and explains the present distribution by *glacialoides* invading the north Pacific in a period of glacial cooling. Entry to the north Atlantic was made through the Bering water gap. This theory is accepted by Fisher (1952, p. 17).

Puffinus assimilis

Puffinus assimilis is an almost circumpolar Sub-antarctic species which has invaded the Sub-tropical region in Australia and New Zealand, where it has differentiated into a number of races (Fleming and Serventy, 1943). In the eastern Atlantic it is one of three petrels which has transgressed the tropics and established itself in the Azores, Madeira and Canary Islands group. The race which survives here, *baroli,* is so far different from the southern *assimilis* and with so many points of resemblance to the tropical *lherminieri* assemblage, that the situation strongly suggests that *lherminieri* is a warm-water derivative from a northward transgressing *assimilis* stock which probably made the passage in pre-Pleistocene times.

The migratory dark Shearwaters of the genus Puffinus

Three species of large all-dark *Puffinus* breed in the southern portions of the Indo-Pacific and migrate across the equator to the northern hemisphere. The widest ranging is *Puffinus griseus,* which breeds from sub-antarctic to warm-temperate waters in the Australian and New Zealand region and off South America. The closely related *P. tenuirostris* is a warm-temperate derivative in southeastern Australia.

P. carneipes now breeds wholly in warm-temperate waters in southwestern Australia, the Tasman Sea and in New Zealand.

Probable allies of this group are the more or less sedentary *P. pacificus* and *P. nativitatis,* now entirely of tropical and sub-tropical distribution.

Pterodroma mollis and its allies

Pterodroma mollis is a breeding species of the southern Indian and Atlantic Oceans, mainly occupying islands in the sub-antarctic zone of surface water. It is of considerable interest in having nesting colonies also in the North Atlantic, at Madeira and the Cape Verde Islands—a distribution pattern paralleling in certain respects that of *Puffinus assimilis* and *Pelagodroma marina,* and an example of a trans-equatorial transgression along the eastern Atlantic route.

Near allies of this species appear to be *Pterodroma brevirostris*, of the sub-antarctic islands of the southern Indian Ocean sector, and *P. inexpectata*, of temperate and sub-antarctic islands of the New Zealand area, and a trans-equatorial migrant to the north Pacific.

Murphy and Mowbray (1951, p. 277) place *P. mollis* as a member of a series of tropical petrels which they call the *hasitata* super-species, and which is referred to in a later section.

STORM-PETRELS

Pelagodroma marina

A temperate and subtropical species, which has transgressed the equatorial belt only in the Atlantic. It is the third member of a series of southern petrels—*Puffinus assimilis* and *Pterodroma mollis* being the others—which has established itself at the Canary and Cape Verde group of islands. In the Pacific Ocean it has penetrated as a breeder only as far north as the Kermadecs, but as a foraging wanderer it has been collected southwest of Cocos Is. (Lat. 4° 31′ N.) and off Ecuador.

In the Indian Ocean it nests as far north as the Abrolhos Islands in southwest Australia.

Fregetta grallaria

Apparently not found in the Indian Ocean but widely ranging in the southern Pacific and Atlantic Oceans, north to the tropics.

GULLS

Southern gulls have only a peripheral distribution along the South American continent and in the Australian and New Zealand region. There has been virtually no colonisation of insular habitats. *Creagrus furcatus*, of the Galapagos, is a strongly marked exception and is presumably an old species.

All gulls probably have an ultimate origin as members of the northern fauna and southern forms are the results of a series of equatorial transgressions. Murphy (1936, p. 1041) has indicated in regard to South American species that "the connection between the coastal gulls of the northern and southern hemispheres is much closer in the Pacific than in the Atlantic," and it is inferred that the colonising route lay along the eastern Pacific.

Larus dominicanus is interesting in being the only representative of the large gulls in the southern hemisphere and in possessing (in conjunction with its Australian derivative, *pacificus*) a circumpolar distribution in sub-antarctic and warm-temperate seas. Opinion differs as to whether it is derived from the northern *L. marinus* (Wetmore) or *L. fuscus* (Dwight). Murphy and Falla are of the opinion, based on voice and behaviour, that *dominicanus* is a black-backed *argentatus* (pers. comm.)

In the southwest Pacific *Larus novae-hollandiae* is a common species in southern Australia and New Zealand, and though found in northern Australia it is sparse and locally absent from considerable stretches of that coastline between the Lacepedes Islands in the west and central Queensland in the east. It has, however, colonised New Caledonia and the Chatham Islands.

3. PAN-TROPICAL ELEMENTS.

The present pan-tropical fauna of the three oceans—Atlantic, Indian and Pacific—is the product of a development of considerable antiquity in a comparatively uniform environment, and is now presented in richest profusion in the Indo-Malayan region. Ekman (1953, pp. 77-79) shows that this is not due to the Indo-Malayan region being the cradle of this fauna, which is basically pan-tropical and descended from a more or less homogeneous Tethys fauna. Climatic and geographic changes in the Miocene and Pliocene dismembered the Tethys fauna and it survived with least drastic change in the present Indo-Malayan area. Ekman in a succinct summary (*ibid.*, p. 79) states: "The present paucity of the Atlantic fauna is not caused by its position on the periphery of an Indo-Pacific centre from which it received only a small part of faunal elements radiating from there. The truth is really that it suffered a deterioration of climate. The faunal richness of the Indo-Malayan region cannot be explained by the assumption that this region became a developmental centre for whole classes and orders of the animal kingdom to a greater degree than, for instance, the Atlantic Ocean. The explanation is rather that in contrast to the Atlantic the Indo-Malayan region has been able to preserve this inherited richness until the present time, and that in addition new forms have been able to develop continuously."

Ekman was dealing primarily with the marine invertebrates and fishes of the coastal shelves, but his conclusions can well be applied to the pelagic sea-birds. The present pan-tropical bird fauna contains, in addition to the primary elements just referred to, a number of immigrants from, mainly, the southern cool-water fauna and which have in several instances undergone secondary differentiation in tropical and sub-tropical waters.

It is convenient, therefore, to consider the Pan-tropical Fauna in two groups: (a) the descendants of forms which have always apparently been tropical in distribution, and (b) forms which are secondarily tropical and which show evidence of descent from southern colonists from the later Tertiary onwards.

(a) The Primary Tropical Fauna

BOOBIES

Sula piscatrix, dactylatra and leucogaster

These three tropical boobies are found throughout the three oceans, where they have sympatric relations. The Panama and Indo-Malayan water gaps have obviously contributed to the distribution pattern obtaining at the present day. However, though all three species nest close to the outer islands of the Indo-Malayan region none actually breed on the islands in the shallow seas within it except on Goenoeng Api in the South Banda Sea. Of the three species, *S. leucogaster* penetrates furthest in this area and, it forages throughout the entire extent of the northern Australian coast. Two species of the Booby group, *S. nebouxii* and *S. variegata,* have differentiated on the west coast of South America, where they have circumscribed ranges.

TROPIC-BIRDS

Phaethon spp.

P. rubricauda and *P. lepturus* have similar relations in the Indo-Pacific as the three Boobies just referred to. *P. rubricaudus* is, however, unrepresented in the Atlantic Ocean.

P. aethereus occurs in the Atlantic and has penetrated to the central eastern Pacific by means of the Panama gap but has not extended widely in this Ocean. Probably through the Tertiary water way between the Mediterranean and Indian Oceans it has obtained entry into the northwest of the Indian Ocean and established nesting stations in the Persian Gulf. It does not occur elsewhere in this ocean. In general, the distributions of *P. rubricauda* and *P. aethereus* are allopatric.

FRIGATE-BIRDS

Fregata spp.

Fregata ariel and *F. minor* have sympatric relations in the tropical zones of all three oceans, the Panama and Indo-Malayan water gaps having facilitated their colonisation of appropriate habitats. *F. magnificens* of the central Atlantic crosses the isthmus of Panama with complete freedom (Murphy, 1936, pp. 859, 920) and has reached a western outpost in the Galapagos.

TERNS

Sterna fuscata and S. anaetheta

These two similar species occur widely in the Indo-Pacific Oceans and through the Panama water gap have peopled the western Atlantic. The distribution suggests the Indo-Pacific basin as the origin of the group. *S. lunata* is a derivative of *S. anaetheta* in the southern central

Pacific. *S. fuscata* and *S. anaetheta* are sympatric and *S. anaetheta* and *S. lunata* are probably allopatric; the records of their breeding together should be re-examined.

Anous spp.

The Noddy Terns (*Anous stolidus*) have a closely similar geographical pattern to the *Sterna fuscata-anaetheta* group just discussed.

The species group, *minutus-tenuirostris*, are now widely separated, one (*minutus*) extensively distributed in the Pacific and Atlantic, the other (*tenuirostris*) confined to two breeding centres in the Indian Ocean. Recent reviewers have tended to consider them as races of one species, but the plumage differences are rather distinct, and it would, perhaps, be better to rank them as having attained specific differentiation, although considering them as semi-species for purposes of zoogeographical discussion.

Gygis alba

Widely distributed in the tropics of the three oceans. It is absent, however, from the Indo-Malayan and northern Australian area, the two nearest breeding colonies being at North Keeling in the Indian Ocean and Palau Island in the Pacific.

Procelsterna spp.

The Grey Noddies, *P. cerulea* and *P. cinerea*, occur only in the tropical Pacific, where the two species have an allopatric breeding distribution, *P. cinerea* being the more southern form.

Sterna sumatrana

An Indo-Pacific form, but in the latter ocean restricted to the west-central group of islands. It is found in the Malayan region, but has not been reported in northern Australia, west of Torres Strait, or in the Timor and Banda seas.

Sterna bergii and S. bengalensis

These two related terns appear to be dominant in the Indian Ocean region. *S. bergii* has the more extensive distribution, and has spread into the cooler waters of southern Africa and southern Australia. It has colonised the central southern Pacific, as a breeding species, east to the Marquesas, but has not crossed the Equator to the north or gone south beyond the Kermadecs.

S. bengalensis has barely entered the western Pacific by occupying the northern part of the Great Barrier Reefs, in Queensland.

Neither species has reached the Atlantic.

(b) Secondary Elements of Ultimate Southern Origin

ALBATROSSES

It is only in the north Pacific that Albatrosses are found outside of the circumpolar Southern Ocean as breeding species. Murphy (1936, p. 633) considers *Diomedea albatrus*, *D. immutabilis* and *D. nigripes* a related group and linked, through *D. irrorata* of the Galapagos, with *D. exulans* and *D. epomophora* of the southern albatrosses. The present distribution of the breeding ranges of the Pacific species points to the eastern Pacific being the colonising path but the transgression of the tropics may have been accomplished when a mid-Pacific upwelling zone existed.

PETRELS

Puffinus lherminieri

Mention has been made of the probable derivation of *Puffinus lherminieri* from a *P. assimilis* stock which made a pre-Pleistocene transgression of the tropics. The subsequent evolution of the *lherminieri* group has been essentially as a tropical form and by means of the Panama and Indo-Malayan water gaps it has now populated the Pacific and Indian Oceans. In the Pacific it nests on a multitude of islands in the tropical and sub-tropical areas. Some of these colonies now approach, through secondary contact, very closely to the northernmost nesting colonies of the presumed ancestral species, *P. assimilis*.

Puffinus pacificus

Puffinus pacificus belongs to a cluster of species of wholly dark shearwaters of southern waters, but itself is wholly sub-tropical and tropical in distribution. It occurs only in the Indian and Pacific Oceans, but is not found, as a breeding species, in the southeastern portion of the latter ocean. There are two discrete populations, separated by the Indo-Malayan islands and Australia (Fig. 3). These two populations do not, however, coincide with the two sub-species which can be recognised (see later).

In Western Australia the species breeds from Carnac Island near Fremantle in the south to Sable Island in the Forestier group, in northwestern Australia. The species is then absent, even as a forager, along the whole of northern Australia, until we pass Torres Straits, when the first breeding colonies occur on numerous islands to Montague Island in southern New South Wales.

Puffinus bulleri, of New Zealand, is a close ally of this species, but which is nearer the ancestral form is uncertain.

Puffinus nativitatis

The breeding range forms an extensive area in the central Pacific, both north and south of the equator, and the species is sympatric with *P. pacificus.*

Bulweria spp.

The origins of *Bulweria bulwerii* and *B. macgillivrayi* are obscure. They occupy the subtropical parts of the North Atlantic and North Pacific and extend into the tropical zone of the Pacific. The genus is unknown as yet in the Indian Ocean. The present distribution suggests that it is a reduced remnant of a former widespread group.

The Pterodroma hasitata complex

Murphy and Mowbray (1951, p. 277) offer some very suggestive comments on the relationships of a group of petrels they refer to as the *hasitata* super-species and which includes the following allopatric forms: *hasitata, cahow, phaeopygia, sandwichensis, externa, cervicalis* and *mollis.*

The parent form of the *hasitata* series appears to be *P. mollis* of the southern oceans. It has made a tropical transgression in the eastern Atlantic, and relatively unaltered populations now exist at Tristan da Cunha, the Cape Verde Islands and Madeira. From the centres in the north Atlantic there has been further differentiation and on the opposite side of this ocean there have developed the races *hasitata* and *cahow.* The Pacific may have been peopled through the Panama water gap leading to the evolution of the form *phaeopygia* (at the Galapagos) and *sandwichensis* (Hawaii). This hypothesis would require the original tropical transgression of the ancestral *mollis* in the pre-Pleistocene and the general pattern of speciation would resemble that of the *Puffinus assimilis-lherminieri* group.

If the north Atlantic and north Pacific forms are the result of independent evolutions from a southern ancestor, not involving use of the Panama water gap, the equatorial transgressions may have occurred as late as the Pleistocene glaciations. In this case the southern Pacific sub-tropical forms, *cervicalis* (Juan Fernandez) and *externa* (Kermadecs), might be off-shoots of this line of development. Solution of the problem awaits more refined taxonomic analysis of the whole group, which is promised us by Murphy and Mowbray (*ibid.*, p. 278).

The Pterodroma arminjoniana complex

Murphy and Pennoyer (1952, p. 35) consider the four species *arminjoniana* (including *heraldica, alba, neglecta,* and *ultima*), to be closely related. *Pterodroma arminjoniana* alone occurs in all three oceans, in subtropical waters, and in the Pacific Ocean the four species have a sympatric breeding distribution, which does not extend far into

the north Pacific. It is possible that the four species are the result of successive invasions from the south, the richness of forms in the Pacific being possibly due to the greater availability of nesting islands as compared with that in the Indian and Atlantic Oceans.

Pterodroma rostrata
Pterodroma neglecta

These two petrels, which are not closely related, occupy various islands in the south Pacific. It is impossible to say more about them at this stage, or to indicate their affinities. Like other members of the genus they appear to be derivatives of southern ancestors.

Pterodroma solandri

A species confined, as a breeder, to the Tasman Sea. It may possibly be a derivative of *Pt. macroptera.*

The sub-genus Cookilaria of Pterodroma

This difficult group, following its earlier clarification by Murphy (1929), has been recently reinvestigated by Falla (1942, p. 111), Fleming (1941, p. 69), and Austin (1952, p. 392). As a result it appears that four species are represented, each with a number of races differentiated in isolated island groups: *Pt. longirostris* (with *pycrofti*), *Pt. leucoptera* (with *brevipes*), *Pt. cookii* (with *defilippiana)* and *Pt. hypoleuca* (with *nigripennis* and *axillaris*). The group is entirely restricted to the Pacific, which may mean that the Panama isthmus may have already closed when the equatorial transgressions took place; thus these invasions could have taken place during the periods of global cooling in the Pleistocene Ice Ages.

The interesting straggler of *brevipes* (breeding only in the Southwest Pacific) which was recorded in Great Britain in 1889 (Witherby, 1941, p. 66) can only be accounted for as a bird which had become hopelessly lost. A similar record of *Pterodroma neglecta* (*ibid.,* p. 62 must be explained likewise. Such birds which are found far from their ordinary beats have probably become attached to wandering and migratory parties of other species (cf. Loomis, 1918, p. 138).

STORM-PETRELS

Nesofregetta albigularis

A sub-tropical species, confined to the Pacific Ocean, and which has just crossed northward over the Equator to breed at Christmas Island.

4. NORTHERN ELEMENTS.

Ekman (1953, p. 186) recognises for the northern hemisphere two marine faunas, a tropical-subtropical and a northern. He points out

(p. 157) that the northern cold-water fauna is considerably richer in the North Pacific than in the North Atlantic, and the explanation is seen in differential climatic conditions, that "during the whole of the Tertiary Period the North Pacific offered much more favourable conditions for the development of a fauna adapted to a cold-temperate climate than the North Atlantic" (*ibid.*, p. 164). Milder climatic conditions in the pre- and inter-glacial periods provided communications between the two oceans.

AUKS

Family Alcidae

The headquarters of the Auks are the circumpolar northern seas, and various species penetrate some distance down both coasts of the north Pacific and north Atlantic Oceans. The north Pacific is particularly rich in species, but only one of them has succeeded in extending any considerable distance south. None, however, has paralleled the performance of many of the southern petrels in transgressing the equatorial belt into the cooler waters of the opposite hemisphere.

The Pacific Auks have colonised the American coast southwards more successfully than they have managed the Asiatic shoreline. Along the American coast 5 or 6 species have penetrated as breeding species to California. These are: *Lunda cirrhata, Uria aalge, Cepphus columba, Aethia aleutica,* and *Brachyramphus hypoleucus.* The last-mentioned has differentiated a form, *B. craveri,* breeding in the Gulf of California, which is the only Auk to reach the Tropics.

This distribution pattern of the auks, with a restricted southward penetration on the west side of the Pacific in comparison with the eastern side, is related to the hydrological pattern of the ocean. This is, approximately, a mirror-image of the hydrobiological situation in the South Pacific.

PETRELS

The Puffinus puffinus complex

Whatever its ultimate origin from a southern ancestry, the spread of this species group in the immediate past has been as a member of the northern fauna. The stimulating analysis by Murphy (1952) would suggest that the centre of dispersal was the eastern Atlantic. A double invasion through the Panama water gap appears to have taken place, first by black-backed forms whose Pacific derivatives are *P. p. auricularis* (breeding off western Mexico) and *P. p. newelli* (breeding in Hawaii). The second invasion was by brown-backed birds, whose Pacific offshoot is *P. p. opisthomelas.*

The place of the New Zealand *gavia* in this geographical pattern is by no means clear. It is a brown-backed ally of *P. puffinus* and Murphy explains its origin (*ibid.*, p. 7) by postulating a spread from the eastern Mediterranean by way of the Mediterranean-Indian Ocean water gap. If this is so the species group has invaded the Pacific basin from the North Atlantic by two routes.

The Puffinus kuhlii group

Alexander (1928, p. 61) and Murphy (1930, p. 11) refer to the close affinity of *kuhlii* (syn. *diomedea*) and *creatopus*, and Murphy in addition associates *leucomelas* in this assemblage.

These forms are only secondarily units of the northern fauna, having probably a southern ancestry, akin to the case of the preceding species.

The secondary cycle of dispersal of the north Atlantic *kuhlii* was probably by way of the Panama water gap into the Pacific, where *creatopus* (breeding in the Juan Fernandez Island) and *leucomelas* (breeding at the Bonins and Pescadores) were differentiated.

STORM-PETRELS

Oceanodroma spp.

The members of this genus are essentially northern forms, which have differentiated into a series of species and races in whose dissemination through the north Atlantic and Pacific, the Bering and Panama water gaps have played essential roles, hence the colonising processes must have begun in the pre-Pleistocene. The taxonomy of the group has proved difficult, the latest revisor being Austin (1952, p. 394) who has made certain parts of the geographical picture much clearer.

O. leucorhoa is a widespread breeding species on both coasts of the North Atlantic and North Pacific, the connection between the two oceans being probably through the Bering water gap.

O. castro is also a breeding form of both oceans, but of more southern distribution, and it would appear that the Panama water gap has contributed to the existing distribution pattern. The Pacific breeding stations are at the Hawaiian, Cocos and Galapagos Islands. This is the only *Oceanodroma* which is certainly known to have transgressed the equatorial belt as a breeder, St. Helena in the south Atlantic being a nesting station.

The north Pacific is inhabited by a complex of related forms which Austin considers all to have reached specific status, two of them being now sympatric. These are *O. melania* (breeding in lower California), *O. matsudairae* (breeding in the Bonins), *O. tristrami* (breeding in the Bonins and Hawaiian Islands) and *O. markhami*, whose breeding

place is unknown. A bird containing an unlaid egg was shot off central Peru and if the breeding station is adjacent this would be a parallel case in the Pacific to *O. castro* in the Atlantic of a transgression of the breeding range through the equatorial belt. This cluster of forms is suggestive of a multiple invasion, via the Bering Gap at each interglacial period, with a southward extension of speciation in the following glacial, the post-glacial form *leucorhoa* not being differentiated.

TERNS

Sterna albifrons and S. nereis

Sterna albifrons appears to be plainly a northern element, with a breeding distribution from the British Isles and the Baltic coasts, southwards, its habitat including rivers as well as marine shorelines. It has disseminated into the Indian Ocean through the Mediterranean-Indian Ocean water ways and the river systems of Asia, reaching the periphery of the western Pacific partly through the Malayan water gap. It now breeds in New Guinea, the Philippines, and neighbouring islands and coasts. In the Australian region it has produced a derivative, *S. nereis*, which is still strictly allopatric with it, and which has spread some distance further into the Pacific—to New Zealand and New Caledonia.

Sterna dougallii

This species is probably a member of the northern element, with its origin perhaps in the North Atlantic. It has failed to pass into the Pacific by the Panama water gap but has penetrated into the Indian Ocean by the Mediterranean-Indian Ocean Gap, and into fringes of the western central Pacific through the Indo-Malayan gap.

Sterna hirundo and S. macrura

Sterna hirundo migrates a considerable distance south along the western Pacific shoreline from its northern breeding grounds, regularly visiting eastern Australian waters, *S. macrura* has a much more extensive migration in the Atlantic sector; in the southern hemisphere it deploys into the southern Indian Ocean.

Other northern terns have limited movements along the Pacific coasts, and cannot strictly be considered pelagic birds.

GULLS

Many northern gulls occupy the coasts of the north Pacific, but none of them has established breeding stations on the numerous islands in mid-ocean or included them in their migrations. *Larus glaucescens* is an occasional wanderer to the Hawaiian Islands.

The relationship of the northern gulls to the southern hemisphere forms was briefly mentioned in the earlier section on Southern Faunas.

Reference was also made to the widespread southern *Larus dominicanus* as a trans-equatorial transgressor of either *L. marinus* or *L. fuscus-argentatus* ancestry.

SKUAS

Catharacta skua

Hamilton (1934, p. 163) has placed the northern cold-water and southern cold-water great skuas as members of one species, a taxonomic treatment supported by Murphy (1936, p. 1006). Though the breeding ranges of the two groups are now widely separated geographically, the Chilean Skua (*C. s. chilensis*) migrates along the western American shoreline to Alaskan waters. The group is probably of northern origin and the southern seas may have been occupied by a colonisation along the east Pacific sea-board, though the northern form, *S. c. skua,* does not now occur in the north Pacific.

GANNETS

The Sula bassana complex

The true classification of the ancestor of the three related temperate-water Gannets, *Sula bassana, S. serrator* and *S. capensis,* is uncertain. It may be a secondary immigrant into the north from the Pan-tropical Fauna.

On the assumption that the group has had its proximate origin in the northern Atlantic the present geographical pattern may have developed as follows:

Sula bassana transgressed through the tropical belt of the Atlantic during a period of global cooling and established itself in southern Africa, where *capensis* became differentiated and colonised eastwards to southern Australia and New Zealand, evolving there into the similar race, *serrator.* This colonisation pattern has also been postulated by Falla (1953, p. 44).

5. SUMMARY REVIEW.

The general picture presented by the pelagic bird faunas of the Indo-Pacific basins is that in the whole of the Indian Ocean and the western and central part of the Pacific we are dealing with one rather homogeneous fauna which consists of the long-established descendants of the Tethyan fauna of the Tertiary. Into this fauna have been injected, from the later Tertiary onward, immigrants from the cool-water faunas of the north and south, but predominantly from the south. These immigrants occur in the Indian Ocean to a much less degree than in the Pacific, in which ocean they are also much more numerous in the south Pacific than they are north of the Equator.

Can one map out well-marked "faunal zones" on the bases of these pelagic bird distributions, demarcating the zones, to use the definition of Ekman (1953, p. 80), "where the most clearly defined change in fauna occurs"?

Such breaks in distribution are readily discernible. Murphy (1936, pp. 65-80) has recapitulated his former well-known thesis that the convergences between water masses of different temperatures are powerful barriers in pelagic bird distributions. His recognition of Tropical, Sub-tropical, Sub-antarctic (Antiboreal) and Antarctic Zones is abundantly demonstrated by the facts. These temperature-determined zones agree in a broad sense with the boundaries of the three main faunas as dealt with in this paper. In the southern hemisphere the sub-tropical convergence is the absolute southern boundary of the Pan-Tropical Fauna, and the northern boundary of the Southern Fauna (cf. the illuminating map of complementary distributions of type birds of these faunas in Murphy, 1936, p. 165). In southern Australia there are anomalies in correspondence between birds and hydrological factors which are referred to in part by Fleming (1941 a).

However, on a broad canvas the picture drawn is a real one. Such concordance between faunas and physical factors emphasises the ancient character of the relationship. Changes in climate which have led to oscillations north and south of the convergences would have resulted in a corresponding ebb and flow of faunal boundaries, and in particular a waxing and waning of the Pan-Tropical Fauna belt. Subdivisions within the areas of main occurrence of the three faunas (such as that between the tropics and subtropics and between the antarctic and subantarctic) would have tended to split the faunas into corresponding units, but these appear never to be as important as the greater break between the Pan-Tropical and the two cool-water faunas north and south of it.

Past oscillations of the convergences have cut off portions of faunas into areas not lived in by their ancestors, or provided temporary bridgeheads across unfavourable stretches of water, over which transgressions were possible. Later when times changed probably most such adventurers failed to survive but those that did now form the immigrant fauna to which reference has been repeatedly made in this paper.

IV. Some Special Problems

1. The Indo-Malayan barrier between the Indian and Pacific Oceans.

Though there are continuous waterways through the maze of islands in the east Indian archipelagoes, between the Indian and Pacific Oceans, a significantly large number of species, characteristic of the tropical zones of both oceans, are absent from them.

No petrel breeds in these waters, not even *Puffinus pacificus* and *P. lherminieri*. The absence of the former is of some moment as the distribution pattern certainly suggests that the Indian Ocean populations must have formerly been connected with those of the Pacific Ocean through this area. At present the nearest breeding colonies, east and west, are separated by some 1,500 nautical miles of sea way. Furthermore, the Indian Ocean birds are sub-specifically inseparable from the bulk of the Pacific Ocean birds. In the Pacific Ocean a distinctive race is recognisable from the region of the Kermadecs (Murphy, 1951, p. 15) though it exists in close proximity, relatively speaking, to other Pacific populations.

The absence of resident pan-tropical petrels in this area is rendered even more curious by the presence in it, as a wintering migrant, of the storm-petrel, *Oceanites oceanicus*, breeding in the Antarctic Region of the far south (Serventy, 1952a, p. 107).

In the shallow seas of this water gap there appear to be no reports of breeding stations of Boobies, Tropic-birds, Frigate-birds, and such terns as *Sterna fuscata, Anous stolidus, Anous minutus* and *Gygis alba*. Goenoeng Api in the Banda Sea (Van Bemmel and Hoogerwerf, 1940, p. 421) is a singular exception. Foraging and wandering individuals and flocks of some of these species, however, do occur, particularly of *Sula leucogaster*.

Along the northern Australian shoreline, from Torres Strait to the Buccaneer Archipelago in northwestern Australia, there is an inexplicable scarcity of *Larus novae-hollandiae*, so plentiful on the remaining parts of the Australian coastline.

It seems that factors are now in control of the situation, accounting for these distributional breaks, which might not have been operating in the immediate or sub-recent past. A superficial search for possible causes suggests that the surface water temperatures might be, at least in part, responsible. According to the data in Schott (1935, pl. 20–23), an extensive band of high water-temperatures exists around New Guinea, northern Australia and out into the Indian Ocean. This is maintained above 28°C. from about November to February and the position of the band correlates very closely with that section of the north Australian area in which *Puffinus pacificus* is absent as a breeding species. According to Dr. J. Gentilli, of the School of Geography of the University of Western Australia, the waters of northern Australia, including the Gulf of Carpentaria, are among the warmest open sea surfaces in the world, approaching that of the Red Sea.

The rich breeding station of Goenoeng Api, a volcanic cone rising directly from the ocean floor in the Banda Sea (Van Bemmel and Hoogerwerf, 1940) suggests that possibly safe nesting sites may be a contributing factor (see Gibson-Hill, 1949, p. 232, and Serventy, 1952 for data on human interference with sea-birds in these seas).

2. ON A SUB-SPECIATION CENTRE IN THE SOUTHWEST PACIFIC.

A study of the distribution of the sea-bird species in the Pacific, particularly of the petrels, indicates various island groups, isolated from each other, where differentiation has gone on to produce fairly distinctive forms. It is not my purpose to make an exhaustive analysis of all of these, but to draw attention, very briefly to one such area in the Southwest Pacific. The idea is put forward with a view to stimulating discussion on the subject and to find out whether the thesis has a wider application than among sea-birds.

Its existence has been emphasised by the recent taxonomic work of Murphy (1951) and Murphy and Irving (1951), on *Puffinus pacificus* and *Pelagodroma marina*, respectively.

The widespread *P. pacificus*, though it has geographically separated populations in the Indian and Pacific Oceans, has not differentiated subspecifically in strict correspondence with these geographical divisions. But there has, however, developed a distinctive race breeding in the Kermadec Islands.

Pelagodroma marina in the Southwest Pacific occurs in the southern Australian and New Zealand regions and in the Kermadecs. The Kermadecs area is occupied by the most strongly marked subspecies though it "is isolated by only short distances from populations characterized by what might be called the world-wide pattern" (Murphy and Irving).

The Kermadecs region has evidently provided conditions which have isolated populations of sea-birds both of more northern and more southern distribution to produce demonstrably different forms. What these isolating mechanisms were is unknown to me, but must undoubtedly be related to the hydrology of the area.

In this general area, though not at the Kermadecs themselves, other local forms have developed. They may possibly be the result of the same set of isolating factors. The present distribution of parent and daughter forms need not necessarily be the same for each species, and the biological fronts between them may have shifted fairly con-

siderably. The cases that have suggested themselves to me are as follows:

Parent Form	Southwest Pacific race
Puffinus pacificus chlororynchus	*P. p. pacificus*
Puffinus assimilis haurakiensis	*P. p. kermadecensis*
Pelagodroma marina maoriana	*P. m. albiclunis*

It is possible that the same isolating mechanisms may have been responsible for the break which led to the differentiation of the two Grey Noddies, *Procelsterna cerulea* in the north and *P. cinerea* in the south. After its evolution *P. cinerea* embarked on an explosive colonisation through the South Pacific.

Speculating even more daringly one might attribute the evolution of *Sterna lunata* from the presumed ancestral *S. anetheta* to the same factors. The two forms may have now overlapped each other in the Southwest Pacific through secondary invasion.

Attention may be directed here to a further subspeciation centre, in New Zealand, and south of the tropical-subtropical area just referred to. In the New Zealand region, including its southern islands, active speciation is shown by the Crested Penguins (*Eudyptes chrysochome* and allies), albatrosses (*Diomedea bulleri* and *cauta*), *Puffinus bulleri* (an ally of *P. pacificus*) and two subspecies of the *Cookilaria* group of *Pterodroma*. If one includes southeastern Australia *Puffinus tenuirostris* enters into the picture as a very close ally of *P. griseus*.

It would appear that in this general area, with its rich development of local species and subspecies outstanding in the Indo-Pacific—a complex system of isolating mechanisms has been at work. The only worker who has attempted an analysis is Fleming (1941a, pp. 146, 152) who has sought the explanation in a "movement of the hydrological convergences due to past climatic cycles and perhaps paleogeographic changes," the suggested causative factors being "changes in the intensity of Antarctic glaciation during the late Tertiary and Pleistocene." The field warrants further prospecting, in particular a deeper study of local modifications of the ocean current system which Fleming regards as responsible for some present-day anomalous distributions in the Australian and New Zealand region.

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FIGURE 1

FIGURE 2

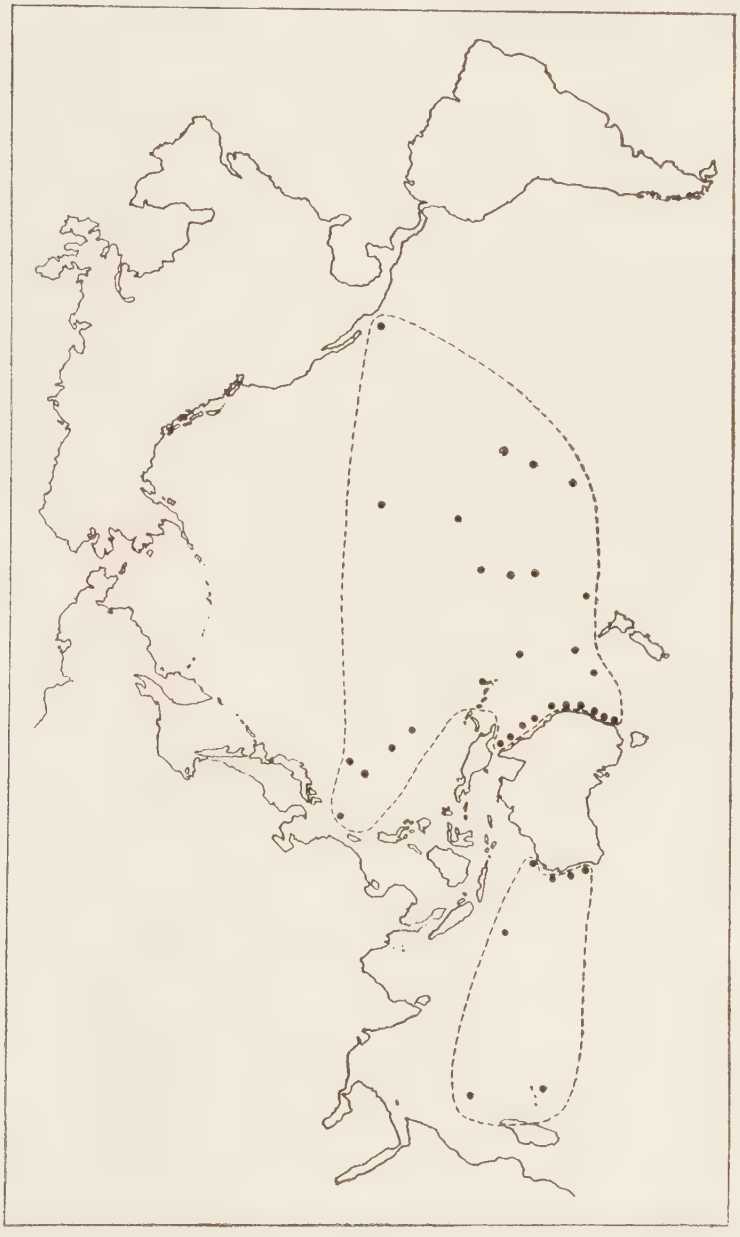

FIGURE 3

SOME DISTRIBUTION PATTERNS REPRESENTED BY THE MARINE ALGAE OF NHATRANG BAY, VIETNAM[1]

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It was close to a century ago that Martens, writing for the German East Asiatic Expedition, summarized for the first and for the last time up to the present, the marine algal flora of Indo-China. Twelve species were listed!

The Indo-China coast extending for over a thousand miles along virtually the entire west side of the South China Sea has remained one of the least known coasts of the world. Upon invitation of the Pacific Science Board and with the support of the U. S. Office of Naval Research,[2] I was privileged to spend three months there during early 1953 in marine algal exploration in the vicinity of the Institut Oceanographique de Nhatrang, Viet-Nam.

The vicinity of the Institut within a radius of five miles offers a remarkable diversity of marine environments including mangrove lagoons, mud flats, sand flats, rocky shores of both coral and intrusive rock, calm lagoons, wave-dashed rocks and sea walls, surge-swept offshore rocks, and varied benthic habitats to depths of over 100 feet. Sampling from each of these environments during the months of January through March resulted in the collection of 224 species of marine plants of which 2% were phanerogams, 8% Myxophyta, 22% Chlorophyta, 12% Paeophyta, and 56% Rhodophyta. Of these, only six species of Rhodophyta occurred exclusively in depths of greater than three meters.

Inasmuch as this investigation represented the first of its kind for the South China Sea region, it was not possible to rely heavily upon any particular work for aid in identifying the plants. Indeed, it was necessary to search virtually the entire literature dealing with tropical marine algae in an attempt to determine the specimens.

This search pointed up sharply the great dearth of information on the marine plants of the vast, tropical areas of the world. In the tropical Indo-Pacific region, for instance, the only reasonably complete marine floras are those of Weber van Bosse for Indonesia, Brgesen's account of the algae of Mauritius, and Taylor's account of the rather

[1] Contribution number 116 from the Allan Hancock Foundation.
[2] These studies were aided by a contract between the Office of Naval Research, Department of the Navy and the National Academy of Sciences (NR 160 175).

poor flora of the Marshall Islands. Besides these, only scattered papers or fragmentary floristic accounts exist, even for such scientifically advanced regions as the Philippines and the Hawaiian Islands.

Not only are these floristic accounts few and incomplete, but many of them lack any consideration of ecological data. Furthermore, numerous problems of nomenclature remain, as well as errors in identification, such that many species are recorded under different names in different areas while unlike species are often incorrectly identified under a single name.

Thus, it must be admitted that our present knowledge of the marine algae of the Indo-Pacific region is hardly sufficient to permit us to attempt to deduce many conclusions regarding distribution, either specific or general.

Despite these difficulties and shortcomings the present study of the marine flora of Nhatrang Bay has revealed some interesting facts regarding distribution which may aid in the thinking in this symposium.

Firstly, of the 224 species known at Nhatrang, about 40% are common ones which are cosmopolitan, pan-tropical or known to be of widespread occurrence in warm seas. From this group of species of broad tolerances little can be deduced as to the affinities of the Nhatrang flora with floras of other regions.

Secondly, our general lack of knowledge of tropical algae is demonstrated in the rather large proportion of new or little known species at Nhatrang (25%). About 7% represent undescribed plants or species referred with doubt to described ones, while about 40 species, or 18%, are hitherto recorded from only one or two other localities. It is particularly noteworthy that of these latter localities a number are very remote from Vietnam, as for example, Easter Island, Juan Fernandez Islands, Tahiti, South India, The Virgin Islands, The Gulf of California, Mauritius, The Canary Islands, Hawaii, New Caledonia, and even Senegal.

It is from among the remaining 35% of the species, whose distributions are somewhat better known and apparently more restricted, that the more interesting correlations may be sought.

In the immediate vicinity of the Institut Oceanographique the most prevalent marine environments are sheltered ones in which the off-shore islands serve as protection from surf-engendering sea-swell. These quiet waters are subject to intense isolation, which accounts for relatively high temperatures, and for diurnal warming of up to 3°C. It is in these quiet lagoon and bay-shore habitats that the greatest proportion of pan-tropical species occurs. It is also there that nearly all of the species which are of occurrence in Indonesia or in the tropical Indian Ocean

are found. Conversely, except for a few cosmopolitan species, very few occur whose ranges extend into temperate climates.

In contrast, only three miles from the Institut is an intertidal locality of markedly divergent ecology and distinctive flora. A short sea wall and associated small area of rough rocks is exposed to the open South China Sea through the broad entrance to Nhatrang Bay, and is subject to heavy surf. This violently agitated locality is densely vegetated with about 25 species of green and red algae. (Phaeophyta were essentially absent). Of these, all but four species, of which three are cosmopolitan, were not found elsewhere in the Nhatrang area. Furthermore, most of the dominant species are of special distributional interest. Of the four most abundant and luxuriant species, all of the genera *Gymnogongrus* and *Grateloupia,* three are characteristic of southern Japan. Also present and of northern distribution centering in southern Japan are *Porphyra crispata* and *Gymnogongrus japonicus.* Another dominant species was *Cladophora perpusilla* which is hitherto known only from equally high southern latitudes at the Juan Fernandez Islands.

The occurrence of this assemblage of species characteristically inhabiting the cooler waters of latitudes higher than 30° seems clearly to reflect the importance of violent agitation in counteracting the latitudinal effects of warming. Thus, the effect of the surf in increasing the amounts of carbon dioxide and oxygen available to the plants appears to compensate for the lower solubilities due to warming.

Another locality of more than ordinary interest in Nhatrang Bay is an exposed ryolite rock about 25 yards in extent lying in the entrance to the bay. It is awash at high tide and subject to constant surge. Its algal flora consists of about 17 species of which all but three were found in no other place in the Nhatrang region. The dominant plants were *Chnoospora pacifica, Dermonema frappieri, Chaetomorpha antennina* and *Ectocarpus breviarticulatus,* all of which are of more or less wide, but discontinuous tropical distribution, being characteristic of just such exposed, surge-swept habitats as obtain on this rock. Such species as *Gigartina intermedia* and *Laurencia tenera* represent a northern component in this flora, while *Ceramium taylorii* of Pacific Mexico and *Mesothamnion caribaeum* of the Caribbean add an interesting but unexplained exotic element.

At this point it should be made clear that the collections at hand represent only the winter flora occuring from January to mid-March. During this season the surface temperatures in Nhatrang Bay range relatively low, from 24° to 26°, compared to the average surface temperature for this north latitude in the Pacific and Indian Oceans which

lies between 26° and 27°. This relative coolness is due to a southward moving current along the west side of the South China Sea and contributes to the extension of northern algal species into such favorable southern localities as the Nhatrang sea wall. During the summer this cooling influence from the north is not felt, and the protected nature of the region allows for appreciable advances in temperature, the maxima of 29–30° being reached in late May and again in mid-September. Unfortunately, data are totally lacking as to seasonal variations and fluctuations in the marine flora.

In summary, two generalities are clear: 1. We are still outstandingly deficient in information about the algae not only of the South China Sea but of the whole Indo-Pacific region. 2. Local variations in ecology account for such extreme diversity between the algal associations of adjoining localities that it is meaningless to suggest affinities for the Nhatrang Bay flora as a whole.

Among these local variations one may recognize at least four distinctive habitats in each of which the dominant algal components represent a different pattern of distribution.

In the upper intertidal zone, above the level of higher low water, and in which the inhabitants are exposed regularly at each ebb tide, an assemblage of species occurs in which the majority are cosmopolitan throughout the temperate as well as the tropical regions of the world.

In the quiet waters of the sheltered bay shores on either side of the Institut most of the dominant algae are not cosmopolitan, but pantropical, having wide, more or less continuous distributions in such commonplace intertidal habitats, but only within tropical or warm seas, particularly in the Indo-Pacific region.

The dominant algae of the surge-swept rocks mentioned above are similarly pan-tropical, but of a markedly more discontinuous pattern of distribution due to their narrower ecological tolerances and consequent restriction to a type of habitat of relatively infrequent occurrence.

Finally, the dominant species of the surf-dashed sea wall at Nhatrang represent a group of algae of restricted distribution in which they are the southernmost outposts of a range centering in temperate southern Japan.

The presence of such a varied flora as has been found at Nhatrang Bay, and of such distinctive habitats with their dissimilar algal inhabitants, all within an area of scarcely five square miles, demonstrates the complexity of the problems of algal distributions in the vast Indo-Pacific region, the more so when it is realized that this five square miles represents only a solitary spot of knowledge surrounded by tens of thousands of miles of unexplored coasts.

SOME PROBLEMS ON MARINE BIOGEOGRAPHICAL MICRO-PROVINCES SURROUNDING JAPAN

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Three characteristic aspects of marine littoral fauna, which have bearings on biogeographical segmentation of Japanese seas, are discussed in this paper.

1) We recognize the continental coastal elements in Japanese bay fauna. These elements have their chief distribution area on the Asiatic coast and, unlike the littoral fauna of open sea coast, their distribution is scarcely influenced by oceanic currents.

2) A large part of the continental coastal fauna has recently declined or become extinct in Japan, and its relics have important meaning on the establishment of biogeographical micro-provinces of the Japanese coast.

3) The benthic communities of bays show regionally different distribution types on the Pacific and Japan Sea sides. We think that typological biogeography is no less important than taxonomic biogeography.

Biogeographical Significance of the Bay Fauna as Compared with the Littoral Fauna of the Open Sea

It is generally accepted that the oceanic current with its own temperature range is the chief factor to determine the biogeographical provinces of the sea. In Japan, the warm Kuroshio Current and the cold Oyashio Current define the biogeographical micro-provinces both horizontally and vertically. The influence of oceanic current is more prominent on the littoral fauna than on the deep sea fauna. Although a distinct boundary between southern and northern faunas is recognized near Inubo-saki, not far from Tokyo, where the Kuroshio Current turns its coastal course to off-shore course, the faunal provinces of the deep sea are less distinct and have wider extent.

The influence of oceanic current on the faunal distribution, however, seems more or less limited to open sea coast, and the bay fauna is quite independent from it in the biogeographical sense. The molluscan species characteristic of Japanese bays have much wider ranges in comparison with those of open sea coast, and Inubo-saki has little meaning as a barrier for their distribution. In this respect the bay fauna

makes an exception of the general rule that shallow water fauna has narrower distribution ranges than deep water fauna.

Most of the molluscs of Japanese bays have their chief distribution area in the Asiatic continent, and they may properly be said to belong to the fauna of continental coast. The ranges of their distribution often cover the coast of south eastern Asia, the China seas including the west coast of Formosa, the Japanese Islands including Hokkaido, and the Russian Maritime Province.

These continental elements are historically the descendants of the fauna of Pleistocene, when the Japanese Islands were more closely connected with the Asiatic continent than at present. The physiological basis for the wide range of distribution may have been acquired through the life in the euryhaline and eurythermal habitat of the bay.

As members of this fauna may be mentioned the following species, most of which being dominant members of benthic molluscan communities of Japanese bays.

Raeta pulchella: Japan incl. Hokkaido, Siam, Borneo, Russian Maritime Province.

Brachidontes sennousia: Japan incl. Hokkaido, Central China, Korea, Russian Maritime Province.

Theora lubrica: Japan incl. Hokkaido; represented by a closely related species in Southeastern Asia.

Paphia undulata: Japan, Siam, China; represented also by a closely allied species *P. textrix* in the continent.

Anomia cytaeum (*A. lischkei*): Japan incl. Hokkaido, China, west coast of Formosa.

Venerupis japonica (formerly misidentified as *V. philippinarum*): Japan incl. Hokkaido, China, Formosa, Korea; represented by *V. indica* in southeastern Asia.

Caecella chinensis: Japan incl. Hokkaido, China.

Zirfaea japonica: Japan incl. Hokkaido, China; represented by a closely allied species *Z. dilatata* in the continent.

Mactra sulcataria: Japan incl. Hokkaido, China coast.

Laternula limicola: Japan incl. Hokkaido, China, Saghalien.

Ostea gigas: Japan incl. Hokkaido, China, west coast of Formosa, Russian Maritime Province.

Littorina brevicula: Japan incl. Hokkaido, China, Korea, Russian Maritime Province.

Veverita didyma: Japan incl. Hokkaido, China.

Mitrella bella: Japan incl. Hokkaido, China.

The similar tendency of wide distribution is recognised in the estuarine and brackish water molluscs, though sometimes replaced by closely

related forms in the continent. *Corbicula japonica* and *Assiminea japonica* may be examples of this category.

From these facts it may be concluded that different parts of the same littoral region with similar depth may belong to different biogeographical provinces according to the kind or system of fauna on which they are based.

Recent Decline of Continental Coastal Fauna from Japan and its Biogeographical Meaning

Among factors to determine the biogeographical provinces, there are geographical distance and ecological conditions of habitat on the one hand and historical processes on the other. The analytical study of the relative weight of these factors is, however, not always easy.

In Ariake Bay on the west coast of Kyushu, there occur several animals which do not appear in other districts of Japan but are very common in the continental coast of Asia. An Enraulid *Coilia ectensis* and a Gobioid *Boleophthalmus pectinirostris* among fishes and *Salinator takii* (represented by allied forms in the continent), *Assiminea latericea* and *Cerithidea ornata* among snails are some of the examples of this category. Based on these facts, Ariake Bay has been regarded to form a special biogeographical micro-province, and this peculiarity was attributed to the geographical proximity between this bay and the continent.

Our recent survey has revealed that there are quite many molluscan species which are found in only a few bays often including Ariake Bay, but are very common in the continental coast. Some of these molluscs are found as semi-fossils in many shell mounds and recent sediments along the Japanese coast. Some of the examples are as follows:

a) Molluscs found in a few Japanese bays at present, but their wide pre-historic distribution has been proved by remains in shell mounds and deposits:

Anadara (*Tegillarca*) *granosa:* Living in Ariake Bay, Inland Sea and Mikawa Bay. Widely distributed in the continental coast. Fossil or semi-fossils in shell mounds or deposits of Sendai in North Japan, Nanao of Japan Sea coast and Osaka Bay.

Trisidos tortuosa kiyonoi: Living in northern Kyushu (Fukuoka Bay and Karatu Bay). Represented by *T. tortuosa* in Indo-China and China coast. Fossils from Toyohasi in Central Japan and Osaka Bay.

Erodona amurensis: Distributed in Hokkaido, Korea, China and Amur Region. Fossils from Toyohasi in Central Japan and Osaka Bay.

b) Molluscs which appear in a few bays at present but are supposed to have had a wider distribution range in Japan, though no fossil remains are at hand. They are common or represented by closely related species in the continental coast.

Glaucome chinensis: Tokyo Bay, Kozima Bay of the Inland Sea, and Ariake Bay.

Sinonovacula constricta: Kozima Bay and Ariake Bay.

Striarca olivacea: Tokyo Bay, Kozima Bay, and Ariake Bay.

Standella pellucida: Kozima Bay.

Cerithidea largillierti: Ariake Bay and Kozima Bay.

Nassarius variciferus: Inland Sea and Northern Kyushu.

c) Molluscs which appear as fossils in Japan, but are represented by closely allied species in the continental coast.

Protapes irrediviva: Totuka not far from Yokohama.

Mabellarca hiratai: an undescribed new Ark-shell from Kagoshima of southern Kyushu.

These facts seem to prove that the continental coastal elements of bay fauna have recently declined or become extinct. The causes of decline are not clear. The possible difference of submarine climate at different localities is not large enough to explain this phenomenon. As a more plausible reason for the decline of this fauna, which belongs to muddy bottom community especially of indentation of bays, may be mentioned the recent change of micro-topography of the Japanese coast.

N. Sakazume (1952) has found that *Anadara granosa,* a bivalve now extinct in Tokyo Bay, is an important member of the shell mounds along the coast of prehistoric Tokyo Bay. It occurs more abundantly in older mounds situated near the head of indentations. As the landing of the bay proceed, the sites of mounds advance toward the mouth of indentations, where this shell becomes a less prominent member of the shell assemblage. It has also been confirmed that in the same site, the lower strata of a mound contain more *A. granosa* than the upper strata.

These facts seem to prove the gradual decline of this bivalve with the progress of landing process in recent geological time. In our opinion, the declining molluscs are preserved as relics in such places as Ariake Bay and a part of the Inland Sea (Kozima Bay as a typical place), where muddy bottom has still a large extent. In Ariake Bay, for an example, the tidal area is so muddy that shell collection by fishermen is made by using wooden runners or mud ski. The declining process seems in progression at present.

Thus in this case the supposed existence of a special micro-province is to be explained neither by the geographical proximity nor by the climatic similarity, but by the survival of some continental elements in a special habitat.

Distribution Type of the Fauna as a Regional Characteristic

In the establishment of biogeographical provinces, the taxonomic list of fauna has been the material of the first importance to be consulted. From the standpoint of ecology and production biology for our economic life, however, the regional characteristics of biomass and distribution types of fauna are no less important than the presence or absence of a particular species or a group of species.

In respect to biomass, our study of bay communities has revealed that within the Japanese Islands the productivity has closer relationships with specific characteristics or individuality of bays such as the mean depth, influents and other ecological factors, than with geographical regions with different submarine climates.

The distribution types of benthic animals differ, on the contrary, in bays of the Pacific and Japan Sea sides. On the Pacific coast, continental molluscan elements have a relatively narrow zonal arrangement in the inmost part of the bay, and the remaining larger area extending from the mouth to the inner part is occupied by the coastal elements of the open sea, showing more or less clear boundary between these two communities. On the Japan Sea side, continental elements occupy most of the area, and only a few open sea elements invade the bay. Furthermore, the continental elements are segregated into two zonal communities: i) the animals which are indices of strong embayment and distributed in the inmost part, and ii) those of moderate embayment occupying the remaining area.

Some of the molluscs of the continental and open sea systems appearing in Japanese bays may be classified as follows:

a) Continental coastal elements which appear in the inner part of bays of both Pacific and Japan Sea sides. They are used as indices of strong embayment.

Theora lubrica, Raeta pulchella, Pahia undulata and *Fluvia hungerfordi.*

b) Continental coastal elements which are quite common in the central and mouth parts of bays of the Japan Sea side, but are rare or absent on the Pacific side. They are the indices of moderate embayment.

Veremolpa micra and *Alvenius ojianus.*

c) Coastal elements of open sea under the influence of the warm Kuroshio Current. They are common in bays of the Pacific coast of southern Japan, but are less prosperous in bays of the Japan Sea and the Pacific coast of northern Japan. They are the indices of weaker embayment.

Veremolpa minuta, Laevicardium undatopicta, Nucula paulula and *Microcirce gordonis.*

The similar tendencies of distribution are found in plankton and perhaps in nekton, too.

The difference of distribution types may be attributed to the different degree of influence of the open sea water caused by tide. The tidal ranges differ on the opposite sides of Japan, which reach more than 1 m. on the Pacific Sea side and about 30–40 cm. on the Japan Sea side.

K. Okamura (1926) published an opinion that the poorness of algal flora of the Japan Sea in comparison with that of the Pacific coast was due to the geologically recent origin of the Japan Sea. Although we have not sufficient reasons to deny this theory, the simpler composition of coastal fauna of the Japan Sea may be more reasonably understood by simpler ecological conditions including a small tidal range than by historical sequence.

We have an opinion that more emphasis should be laid in future on the biogeographical study from quantitative and typological viewpoints than from the taxonomic standpoint.

Summary

1) In Japanese bays, there occur the faunal elements of the continental coast, which have much wider distribution ranges than those of the open sea coast and their distribution is little influenced by the oceanic currents.

2) Some of the continental coastal animals have recently become extinct or remain as relics in some special bays. This fact is proved by the study of shell mounds and it has an important meaning in the segmentation of marine biogeographical micro-provinces around the Japanese Islands.

3) The bay communities have regionally characteristic distribution types, and we have an opinion that the biogeography based on taxonomic differences is only one side of biogeography.

THE MARINE MOLLUSCA OF THE KERMADEC ISLANDS IN RELATION TO MOLLUSCAN FAUNAS IN THE SOUTH WEST PACIFIC

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The demarcation and nomenclature of Australasian and South-West Pacific biogeographical regions have been largely a matter of rather haphazard incremental growth. Whitley (1932, p. 167) published a map showing the Australasian regions based upon studies by Hedley Iredale, May, Hull, Finlay, and Cotton. Unfortunately the journal in which Whitley published is not widely known overseas, and the compilation he so adequately presented does not appear to have attracted much notice. The Schilders, for example, (1938–39) in their monumental study of the Cypraeidae either did not know of Whitley's scheme (or any of the previous work on Australasian faunal regions) or ignored it. Iredale and Allan (1940, p. 445) published a map showing "former Zoological Land connections with Lord Howe Island" which, together with their text, implies some interesting modifications of Whitley's scheme and indicates the probable origins of the faunal regions.

In the meantime, Powell has added a northern faunal zone to the Neozelanic region, the Aupourian (Powell 1937, p. 156; 1940, p. 205). There is little difficulty involved in delimiting the broad faunal provinces of New Zealand and Southern Australia (though the actual boundaries have not been determined in a number of cases). But the Dampierian (Western and North-western Australia) and Solanderian (Great Barrier Reef) and New Caledonia, Lord Howe, Norfolk, and the Kermadec Islands are on the outskirts of the widespread Indo-Pacific marine fauna and are influenced to a varying extent by it. The truly marginal areas of Lord Howe, Norfolk, and the Kermadecs have always presented problems of classification. Each can quite easily be considered a distinct faunal province but the determination of the biogeographical region to which each belongs has proved difficult.

In the belief that study of these marginal areas may throw considerable light upon the methods to be used in subdividing the Indo-Pacific marine fauna, the marine mollusca of the Kermadecs have been sub-

jected to a new analysis. In any case in any scheme for subdivision of the Indo-Pacific these marginal areas must receive due consideration.

Oliver (1915) presented an account of the mollusca of the Kermadecs. Since then changes in nomenclature have altered some of the relationships and a more detailed analysis has been found desirable. Oliver tabulated the relationship of the Kermadec mollusca under the following heads: Endemic, Polynesian, New Zealand, and Pelagic. The results so obtained give a biassed picture of relationships. No account was taken of Australian relationships, nor was any distinction made between those species occurring in Australia, New Zealand, and the Kermadecs, and those found in New Zealand and the Kermadecs only. These latter species alone form the neozelanic element in the Kermadec fauna, or the Kermadecian element in the New Zealand fauna depending on the direction of original migrations. Lord Howe and Norfolk have been grouped into a Phillipian province and included in the Neozelanic region by Whitley. It is therefore necessary to consider the fauna of the Kermadecs in relationship to that of the Phillipian province. For the above reasons the marine mollusca of the Kermadecs have been analysed under the following heads: Endemic, Occurring in New Zealand, Occurring in New Zealand but not in Australia, Occurring in Australia, Occurring in Australia but not in New Zealand, Occurring in Norfolk and/or Lord Howe Islands, South Pacific and Pelagic (or drift shells).

	Total	Per cent	Gastropoda	Pelecypoda	Amphipoda	Cephalopoda
Endemic	85	34	63	7	8	7
New Zealand	22	9	15	7	—	—
N.Z. (but not Aust.)	8	3	3	5	—	—
Australia	67	27	55	12	—	—
Aust. (but not N.Z.)	50	20	40	10	—	—
Norfolk and/or Lord Howe	31	12	27	4	—	—
South Pacific	62	25	47	15	—	—
Pelagic (or drift)	29	12	20	—	—	9

The endemic element (one third) is thus seen to be the strongest represented. The essentially New Zealand element is very small (8 species), indicating that although 22 species are common to the Kermadecs and New Zealand, 16 of them are also found in Australia. It is most probable that these species have been derived from Australia rather than from New Zealand.

The eight species found in the Kermadecs and New Zealand, but not in Australia are: *Xenophalium royanum* (Iredale), *Poirieria zelandicus* (Q. & G.), *Neothais smithi* (Brozier), *Monia zelandica* (Gray),

Cosa costata (Bernard), *Hoschstetteria meleagrima* Bernard, *Mytilus canaliculatus* Martyn, and *Modiolaria impacta* (Hermann).

Upon close examination this already weak link proves weaker still. *Poirieria* was recorded by the *Challenger* from 1,100 metres off the Kermadecs and these shells have not been critically re-examined. *Mytilus* was recorded by Suter but no specimens have been seen in quite extensive collections. Such a species would undoubtedly be well represented in beach collections if it were present. The *Monia, Modiolaria, Cosa,* and *Hochstetteris* are all doubtfully the same as the New Zealand forms. The *Xenophalium* occurs very rarely in northern New Zealand waters, and *Neothais smithi,* though abundant at the Kermadecs and occurring at Lord Howe and Norfolk, is but a rare straggler in New Zealand waters.

From the above it appears certain that molluscan dispersal movements are from the Kermadecs to New Zealand, at least within recent times.

A number of the genera occurring at the Kermadecs are otherwise endemic to New Zealand e.g. *Eudoxochiton, Onithochiton, Maorichiton, Austronoba, Haurakiopsis* and *Pinnoctopus* (?). If these genera were originally derived from New Zealand it must have been at some time in the Tertiary, since in all cases the forms at the Kermadecs have differentiated specifically. In all these cases there is no palaeontological evidence available to show whether dispersal took place in the direction mentioned or from the Kermadecs to New Zealand.

It thus becomes apparent that the marine molluscan fauna of the Kermadec Islands has little relationship to New Zealand but has been derived from a number of other sources. The geological history of the group and their comparative isolation have been long enough for a large number of endemic forms to evolve. Some of these are large and characteristic shells e.g. *Scutellastra, Tectus* and the species of *Cellana,* and *Siphonaria.* Indo-Pacific and Australian elements are well represented and a number of forms are shared with Lord Howe and Norfolk Islands. It is difficult to assign the group to any zoogeographic region and a similar difficulty occurs with the neighbouring Lord Howe and Norfolk Islands. The marine fauna of these three marginal areas represents an interplay of factors such as geological age, distance from neighbouring land, the direction of surface water movements and larval motility and duration.

Iredale and Allan (1940) suppose that the very evident relationships between the marine mollusca of Lord Howe and New Caledonia date back to a period when there was a land connection between the two. The presence of *Placostylus* in both areas is fairly conclusive

evidence of a former land connection (possibly quite early in the Tertiary) but a number of the mollusca may quite well have been derived at a later period by transoceanic migration. The slight Australian element could also have been similarly derived. Geographical propinquity coupled with direction and intensity of ocean currents can be as important as a land connection in the past.

Almost a tenth of the molluscan fauna of the Kermadecs are pelagic in habitat, but this is a sign of the comparative paucity of the molluscan fauna. On the other hand quite a large percentage of the Indo-Pacific mollusca present at the Kermadecs will probably prove to have highly motile larval stages.

The figure shows in simplified form the probable relationships of the marine molluscan faunas of the various land masses in the South-west Pacific and points up the difficulty of assigning any of the isolated areas to a neighbouring biogeographical area. The answer to the problem may well be to designate a South-West Pacific biogeographical region with a large number of subregions, e.g., Kermadecian for the Kermadec Islands, Philippian for the Lord Howe and Norfolk Islands, Neozelanic for the New Zealand and Australian, and Montrouzierian for New Caledonia with subdivision into provinces when necessary (e. g. Australia and New Zealand).

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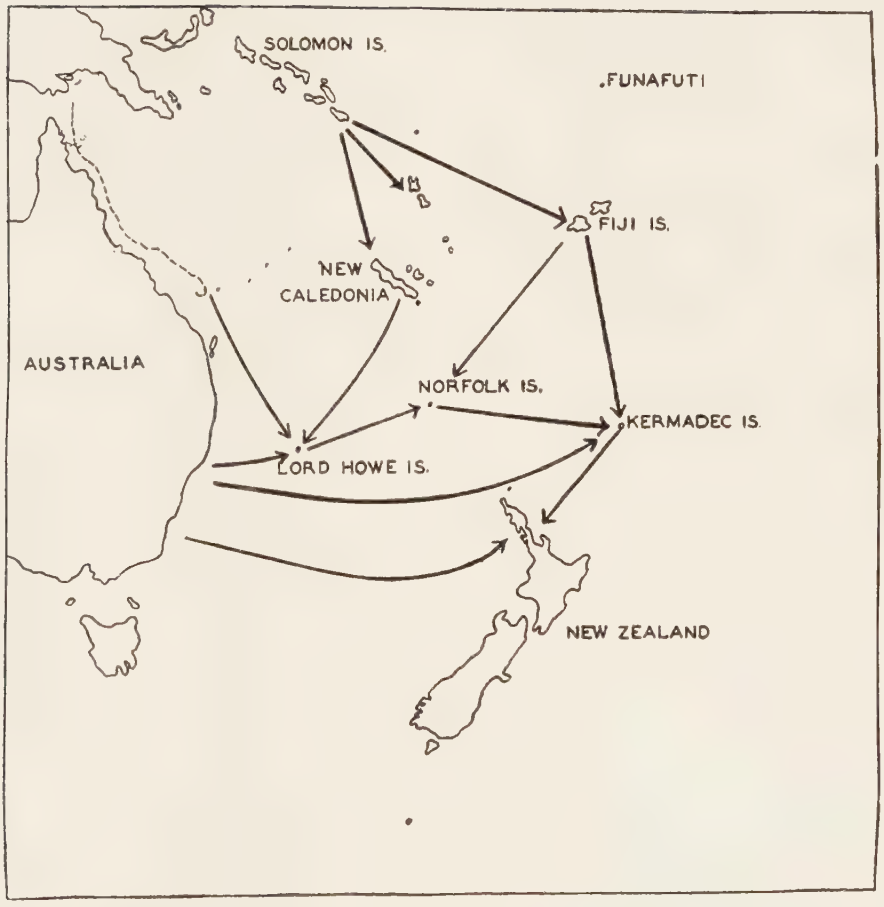
SOLOMON IS.
FUNAFUTI
FIJI IS.
NEW
CALEDONIA
AUSTRALIA
NORFOLK IS.
KERMADEC IS.
LORD HOWE IS.
NEW ZEALAND

THE GEOGRAPHICAL VARIATION OF EARLY EMBRYONIC PROCESSES IN MARINE EGGS

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A. Introduction

In a recent paper I have pointed out that the eggs of the marine Polychaete *Hydroides norvegica* have probably different cleavage patterns in the North Sea and in the Mediterranean (Wolsky 1952). Whereas in Kristineberg (near Fiskebäckskil), on the west coast of Sweden, the early cleavage was found to be spiral and equal, an earlier observer, working at Cette (Sete) on the Mediterranean coast of France, found it orthoradial and unequal (Soulier 1898, 1902). It was suggested that this difference may be due to a differentiation of physiological races within the species, which occupy different regions and differ from each other in an early embryonic character of their eggs. A further study of the literature has revealed that the occurrence of such egg races, differing from each other in some physiological properties and early developmental processes is a widespread phenomenon. Moreover, these races seem to be well adapted to the environmental conditions of the geographical area in which they occur. This not only corroborates the view about the existence of two egg races in *Hydroides norvegica*, but also provides a basis for a more profound explanation of the phenomenon and for some generalizations. In the following the relevant facts will be reviewed first, followed by some theoretical considerations and their application to the case of Hydroides.

B. The Relevant Facts Concerning Physiological Egg Races

(1) The factor which seems to have the most profound influence on the physiological properties and early developmental processes of eggs is temperature. This is obvious, considering the fundamental correlation between temperature and the properties of living matter, especially the velocity of biochemical reactions which make out the bulk of early embryonic processes (cf. Belehradek 1935). In addition, in the case of equatic eggs, salinity (osmotic pressure) of the medium is just as important as temperature, and the two factors act synergetically. Higher

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salinity has the same effect as lower temperature (cf. Heuts 1947b, Koch and Heuts 1943).

(2) The most immediate adaptive response of the organisms to these factors is the adaptation of the tolerance range and optimum of their eggs to the conditions existing in their environment. Eggs produced in warmer waters tolerate higher temperatures and have a higher optimum temperature for their normal development than eggs from colder waters. This was shown both for egg races within the same species and for eggs of closely related species inhabiting different regions (cf. Runnstrom 1927, 1929, 1936, Moore 1939, 1942a, b, 1944, 1949). Similar differences were found between egg races from localities of different salinity in respect to adaptation to osmotic pressure (cf. Heuts 1947b, 1949).

(3) Certain physiological properties of eggs, in particular the rate of cleavage, are adapted to temperature (and salinity) in a regulative-compensatory manner. That is, the adaptation tends to minimize the effect of extreme environmental influence and to establish a uniform physiological standard under different conditions. Egg races from colder waters have the same rate of cleavage at the average temperature of their normal environment as egg races from warmer waters at the higher average temperature of their normal habitat (cf. Munro Fox 1936, Moore 1939, 1942a, 1949).

(4) Certain other physiological-biochemical properties of eggs, notably the rate of the production of morphogenetic or "organ-forming" substances (i.e. the beginning of differentiation which is often called "chemo-differentiation") do not show such regulative-compensatory adaptation. On the contrary, this seems to be influenced directly by temperature (and salinity), so that morphological differentiation proceeds quicker in warm regions (or regions of low salinity) and slower in cold regions (or regions of high salinity). In consequence there may arise some morphological differences between adult specimens of the same species, collected from different localities differing in their average temperature and/or salinity, which can be reproduced artificially in a laboratory by controlling temperature and salinity during *embryonic* development. This has been shown for example for the so-called meristic characters of fishes, such as number of vertebrae, number of fin-rays, etc. (cf. Heuts 1946, 1947a, b, 1948, Hubbs 1922, 1926).

C. Some Theoretical Considerations Concerning the Correlation between Cleavage and Differentiation

(1) From the foregoing it seems that in egg races the processes of cleavage are adapted to temperature in another way than the processes

of the production of morphogenetic substances, i.e., differentiation. The former tend to be constant under various climatic conditions whereas the latter follow exactly the differences of temperature, i.e., will proceed slower in colder and quicker in warmer climate.*

(2) This means that various stages of cleavage will not coincide in all egg races with the same stages of morphogenetic processes. In colder waters morphogenesis will proceed slower in relation to cleavage than in warmer waters. Therefore a certain stage of differentiation which in a race of a warmer region is reached, say in the 8-cell, or 16-cell stage, will be reached in a race from a colder region perhaps only in the morula or blastula stage.

(3) The relative time of differentiation defines also the mode of determination of subsequent developmental processes in the various egg races. A race with relatively early differentiation, i.e., an early production and segregation of morphogenetic substances, will have a mosaic type of determination, in which the fate of the blastomeres is fixed from the beginning. In a race in which such morphogenetic processes start relatively late and progress slowly, the development will be of the regulative type; i.e., the morphogenetic potency of the blastomeres is in the beginning greater than their final role.

(4) This difference may also determine the mode of cleavage as it is generally assumed that "mosaic" eggs have a tendency to unequal cleavage, whereas in regulative eggs the cleavage is usually equal (cf. e.g. Lillie 1901, Chen and Pai 1949). The explanation is, of course, that in the mosaic eggs there are invisible differences between the various regions of the cytoplasm from the beginning, due to a precocious production and segregation of morphogenetic substances and these cause differences in the shape and size of blastomeres. In the regulative eggs the cytoplasm is in the beginning more or less homogeneous and consequently the blastomeres will be approximately equal.

D. Interpretation and Generalization of the Case of Hydroides Norvegica

(1) The above theoretical considerations are in good accordance with the findings about the mode of cleavage in Hydroides. The cleavage is equal in the North Sea, i.e., in a colder region, and unequal in the Mediterranean, which is definitely warmer. On the basis of the foregoing the explanation must be that in the Mediterranean race the process of differentiation begins relatively early and the cytoplasm of the eggs must be differentiated into heterogeneous regions before the cleav-

* Findings of Koehler (1912) seem to indicate that the two sets of processes have different temperature coefficients even within the same egg, which shows that they are of different nature (Koehler, l. cit. page 273).

age begins, so that the blastomeres will be of different size. In the North Sea race, on the other hand, the egg cytoplasm must be practically homogeneous during the first stages of cleavage and consequently the blastomeres will be more or less equal.

(2) The further fact that the cleavage of Hydroides is orthoradial in the Mediterranean race and spiral in the North Sea race may be perhaps also explained by differences of temperature. Knowing that the two types of cleavage depend to a certain extent on differences in the cohesion of the blastomeres (cf. Gray 1931), and knowing that calcium plays a decisive role in this cohesion (cf. Herbst 1900), one may speculate if the difference in the cleavage pattern is due to differences in the availability of calcium in the waters of the two regions, caused by differences of temperature. However, this trend of thought has its serious obstacles and for the time being no satisfactory explanation can be offered to account for the phenomenon.

(3) The explanation of the differences in the mode of cleavage of Hydroides can be generalized and a tentative prediction put forward concerning physiological egg races. It can be predicted that marine species occupying large geographical areas, within which there are differences of climate, probably have physiological egg races differing from each other in the type of the determination of their developmental processes and their pattern of cleavage. In colder regions the eggs of such species should be of the regulative type and their cleavage equal. In warmer regions one should expect to find egg races of the same species with a "mosaic" character and unequal cleavage pattern. The same difference should be found between eggs of closely related species occupying different geographical areas, in which the climate is different. —These predictions could be verified, or disproved by further investigations on a broad comparative zoogeographical basis.

ADDENDUM AT PROOF-READING

Since this paper was submitted I have had an opportunity to study the mode of cleavage of *Hydroides norvegica* in the Mediterranean (cf. Wolsky, A. "Mode of cleavage of the eggs of *Hydroides norvegica* in the Mediterranean," *Nature* 176, 75, 1955). It turned out that the difference between the eggs from the North Sea and from the Mediterranean is not so sharp as assumed on the basis of Soulier's categorical statement (Soulier 1898, page 1662) "chez Hydroides . . . . la segmentation est inégal au debut". Measurements have shown that the cleavage is indeed somewhat more unequal in the Mediterranean than in the North Sea, but it was impossible to decide whether this difference is statistically significant. On the other hand, definitely no difference was found

between the two races as regards the spirality of the cleavage. The cleavage is of the spiral type from the beginning both in the Mediterranean and in the North Sea. This makes paragraph D (2) above obsolete and no further attempts will be needed to explain a phenomenon, which does not exist. —However it is interesting to note that recently W. Ludwig and H. W. Ludwig have reported physiological differences in the regenerative potency of *Hydroides norvegica* from different localities, such as Naples, Plymouth and Cold Spring Harbor (Ludwig, W. and H. W. Ludwig "Untersuchungen zur kompensatorischen Regeneration an *Hydroides norvegica*" *Roux' Arch. Entwicklungsmech.* 147, 259, 1954). It is also noteworthy that in another marine Polychaete, *Ophryotrocha puerilis,* Bacci and La Greca have described slight physiological and morphological differences between the races inhabiting the North Sea and the Mediterranean respectively (Bacci, G. and M. La Greca "Genetic and morphological evidence for subspecific differences between Naples and Plymouth populations of *Ophryotrocha puerilis*" *Nature* 171, 1115, 1953). Finally it should be mentioned that Steinböck and Ausserhofer have found in a primitive fresh-water flatworm, *Prorhynchus stagnalis,* two fundamentally different types of cleavage within the same species, one equal and orthoradial, one unequal and spiral.* These findings seem to corroborate in one way or another the general conclusions of this paper.

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November 20, 1953

SYMPOSIUM ON GENERAL CIRCULATION IN THE PACIFIC

Convener: Dr. Koji Hidaka, Geophysical Institute, Tokyo University, Tokyo, Japan.

Secretary: Mr. Alfonso R. Sebastian, Bureau of Fisheries, Manila.

PROCEEDINGS

Session started at 9:00 A.M. Dr. Hidaka remarked that although the symposium would be about the general circulation of the Pacific, some papers to be presented would touch on other aspects of physical oceanography. He suggested a limited speaking time of 10 to 15 minutes for every one who would present a paper. He made an exception in the case of Dr. Pettersson who had requested for longer time.

Papers read and discussions that followed were:

1. "Theoretical Studies on the General Circulation of the Pacific Ocean" by Dr. Koji Hidaka, Tokyo University, Tokyo; Department of Oceanography, Texas A. & M. College, College Station, Texas. Read by Dr. Hidaka. With slides.

Discussion

Tully—In your calculations do you come to a level of no motion?

Hidaka—Yes, at 10 D_z.

Spilhaus—Do your calculations show the Equatorial Counter Current underneath the Equatorial Current?

Hidaka—We have not yet reached that in our studies.

Hidaka (in answer to question by Uda)—This theory assumes that the mixing coefficient is constant.

2. "A Contribution to the Theory of Upwelling and Coastal Currents" by Dr. Koji Hidaka. Read by the author. With slides.

Discussion

Tully—Is this theory for infinite depth?

Hidaka—Yes. For finite depth it becomes more complicated.

Spilhaus—Do your computations hold approximately, as long as the depth is 2D?

Hidaka—Yes.

Schmidt—For what latitude were these computations made?

Hidaka—Latitude 30°.

3. "Surface Waters off the Canadian Pacific Coast" by J. P. Tully and L. A. E. Doe, Pacific Oceanographic Group, Fisheries Research Board of Canada, Nanaimo, B.C., Canada. Read by J. P. Tully. With slides.

Discussion

WOOSTER—What is the West Wind Drift referred to, the Aleutian Drift or the West Wind Current?

TULLY—There is a change of properties through the Aleutian Drift and the West Wind Current.

PETTERSSON—We have been struggling for 20 years on a synoptic representation off the northwest coast of Europe; it becomes more and more complicated. The North Pacific Ocean must be an ideal 'hunting ground', better than off the northwest coast of Europe.

TULLY—We do not expect eddies to be constant; if we could once see a whole picture then we can realize the general principle, although we can say this is only transient.

4. "Circulation near the Washington Coast" by Clifford A. Barnes and Robert G. Paquette, Department of Oceanography, University of Washington, Seattle, Washington, U.S.A. Read by Dr. Barnes. With slides.

Discussion

DIETZ—Is there mixing or sinking?

BARNES—There is no evidence. Water coming out is stable. The very shallow surface layer is turbid at times.

SPILHAUS—Have the G. E. K. velocities been corrected for the group factor?

BARNES—Yes.

5. "U. S. Navy Contributions to the Study of Pacific Circulation" by John Lyman, Director, Division of Oceanography, U. S. Navy Hydrographic Office, Washington, D.C., U.S.A. Read by title only.

6. "On the Variation of Kuroshio near the Japan Islands" by D. Shoji and K. Suda, Hydrographic Office, Tokyo, Japan. Read by Dr. Suda. With slides.

7. "Sedimentation in the Deep Sea" by Hans Pettersson, Oceanografisca Institutet, Göteborg 4, Sweden. Read by the author. With slides.

Discussion

BERLAGE—How are the cores taken home?

PETTERSSON—In long steel tubes in sections (stainless steel or brass).

8. "Some Characteristics of Sea Water Structure" by John P. Tully, Pacific Oceanographic Group, Nanaimo, B. C., Canada. Read by the author.

Discussion

UDA—What can you say of the influence or stratification by frontal transport or movement of cold water invading as in the case where Oyashio and Kuroshio come together?

TULLY—This is a technique for marking or examining the structure. Using the technique emphasizes the limits of such invasion.

HIDAKA—Does this analysis apply to other parts of the ocean?

TULLY—Our office is preparing statistical analysis of 5,000 samples from all over the world.

HIDAKA—I think somebody should work on the theoretical explanation.

AFTERNOON SESSION

9. "On the Circulation in the North Pacific in Relation to Pelagic Fisheries" by Michitaka Uda, Tokyo University of Fisheries, Tokyo, Japan. Read by the author. With charts and graphs.

Discussion

TULLY—Last year people were working on correlation of occurrence of seals with this study. What latitudes are here involved?

UDA—41° N Latitude.

10. "The Topography of the Sea Surface in the Region of the Philippines" by Herbert W. Graham, U. S. Fish and Wildlife Service, Woods Hole, Massachusetts, U.S.A. Read by Dr. Dahlgren. With slides.

11. "Recent Oceanographic Exploration in the North and Equatorial Pacific Ocean" by Warren S. Wooster, Scripps Institution of Oceanography, La Jolla, California, U.S.A. Read by the author. With slides.

Discussion

UDA—Is a boundary or line of discontinuity seen between the Peruvian and the Equatorial Counter Currents?

WOOSTER—We never saw one along the north wall of the Peruvian Current.

TULLY—Is a composite picture made up from all the expeditions?

WOOSTER—Yes, but rather poor, from Japanese data, some U. S. Navy data, Carnegie data, Sardine Research data, etc.

12. "Basin Waters of Southern California" by K. O. Emery, Allan Hancock Foundation, University of Southern California, Los Angeles, California, U.S.A. Read by the author. With slides.

Discussion

BARNES—Any evidence of any pattern of circulation below the sill?

EMERY—None within individual basins. Most upwellings occur on the basin along the continental slope.

BARNES—Any tilt along the slope?

EMERY—No. Only indications of seiches within the basin.

EMERY (in answer to question by UDA)—In one of the deep basins there was a distinct rise of actual temperature with depth.

DIETZ—Any indications of the effect of sediments on the slope?

EMERY—Yes. But we have no information on channels running down the slope.

13. "An Oceanographic Model of Puget Sound" by Clifford A. Barnes, John H. Lincoln, and Maurice Rattray, Jr., University of Washington, Seattle, Washington, U.S.A. Read by Dr. Barnes. With slides.

Discussion

TULLY—Is it advisable to make a model on a bigger scale?

BARNES—Yes, possibly on a space about four times as big.

TULLY—We have a corresponding model about 200 miles from that of Dr. Barnes. With larger scale we get natural turbulence on rather lower levels of flow, and a little more room to work in, as on salinity gradients. One other trick would be the use of color photography (with dyes).

14. "Daily Seawater Observations on the Pacific Coast of Canada" by H. J. Hollister, Pacific Oceanographic Group, Nanaimo, B.C., Canada. Read by J. P. Tully.

Discussion

REVELLE—Is there really an association between daily sea water conditions and the fisheries?

TULLY—Yes, as in the case of the tuna fisheries.

TULLY (answer to question by Dr. Bruun)—In the studies of correlation with fisheries, there are actually more in Washington and California than in our own country. These studies were, in fact, recommended by Dr. Helland Hansen in 1943.

15. "A Study of Local Variability in Marine Sediments" by Richard G. Bader, Department of Oceanography, University of Washington, Seattle, Washington, U.S.A.

16. "Secular Variation of the Annual Mean Sea Level along the Japanese Coasts" by Masamori Miyazaki, Kobe Marine Observatory, Japan. Read by title only.

Session adjourned at 4:36 P.M.

November 21, 1953

Session resumed at 9:13 A.M.

Papers read and discussions that followed:

17. "Submarine Canyon Investigations" by Francis P. Shepard, Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A. Read by Dr. Dietz.

18. "Surface Temperature and Salinity in the Southwest Pacific Ocean" by D. M. Garner, Oceanographic Observatory, Department of Scientific and Industrial Research, Wellington, New Zealand. Read by Dr. Rochford. With slides.

Discussion

UDA—What would you call the southward current east of New Zealand?

ROCHFORD—I do not know of the existence of one, as verified by the isotherms.

UDA—Can there not be one due to upwelling?

ROCHFORD—I don't think so.

19. "Secular Trends at East Australian Coastal Stations: 1942–1952" by D. J. Rochford, Marine Biological Laboratory, Cronulla, N. S. W., Australia. Read by the author. With slides.

Discussion

UDA—Is there any influence of the flow of Arctic Water mass to increase the nutrients in Australian coastal waters?

ROCHFORD—Recent discoveries in the region close by suggest there isn't very much.

(Dr. Rochford exhibited an apparatus for hydrological observations).

20. "Recent Developments in Tidal and Tidal Current Measurements" by U. S. Coast and Geodetic Survey. Read by Capt. Andres O. Hizon, Director, Bureau of Coast and Geodetic Survey, Philippines. With charts.

Discussion

DIETZ—Do you have these instruments described in the paper in your country?

HIZON—No.

TULLY—Would there be any trouble in the buoy due to oscillations and other effects?

HIZON—I haven't had the opportunity to work on these instruments as yet, but I have read that the magnetic system is statically and dynamically balanced. There is also a great tampering effect.

(Session temporarily suspended at 10:35 to enable members to attend showing of Dr. Woodcock's film on "Bursting of Spherical Bubbles on Sea Water Surface" at the Liberal Arts Theater, University of the Philippines. Session resumed at 3:35 P.M.)

21. "On the Minimum Oxygen Layer in the North Pacific Ocean" by Takeo Kawamoto, Kobe Marine Observatory, Japan. Read by Y. Miyake.

22. "A Study on the Property of the Coastal Water Around Hachijo Islands" by Y. Miyake, Y. Sugiura, and K. Kameda, Meteorological Research Institute, Tokyo, Japan. Read by Y. Miyake.

Discussion

UDA—What causes the diurnal variation in oxygen, salinity, and silicates?

MIYAKE—Phytoplankton for the oxygen, and tides and large horizontal disturbances for the silicates and chlorinity.

23. "On the Oceanographical Conditions of the Sea near the Fixed Point 153°E, 39°N, in the North Pacific Ocean" by M. Nakano, M. Koizumi and J. Fukuoka, Central Meteorological Observatory of Japan, Tokyo, Japan.

24. "Distribution of Copper and Zinc in Sea Water" by Yoshimi Morita, Faculty of Science, Nagoya University, Japan. Read by Y. Miyake.

25. "Abnormal Summers in the Peruvian Coastal Current" by Erwin Schweigger, Compañia Administradora del Guano, Lima, Peru. Read by Dr. Lovell.

Discussion

WOODCOCK—Are there very marked and significant meteorological occurrences in the region of upwelling?

LOVELL—Yes, also violent electrical storms and abnormal change of wind.

HIDAKA—What is the size of the gyro?

LOVELL—Ten to fifty or sixty miles, depending upon the area.

UDA—Is there upwelling all along the coast?

LOVELL—No. There are certain local regions where upwelling is not appreciable.

HIYAMA—What relationships exist with the sardine fishing grounds?

LOVELL—Sardines in general abound all along the coast where you have the coolest water. Areas of upwelling have more sardines than any other. As for the tunas, skipjacks are found in more oceanic (warmer) waters, 17°–18°C and yellowfins in the margins of warm water intrusion, about 16°C.

HIYAMA—What are the particular fishing seasons?

LOVELL—For sardines, southern summer, December to March or April; for tunas, January at the earliest.

26. "Quantitative Determination of Tungsten and Molybdenum in Sea Water" by Masayoshi Ishibashi, Tsunebobu Shigematsu and Yasuharu Nakagawa, Kyoto University, Japan. Read by title only.

27. "A Study on Temperature and Salinity of the Surrounding Waters of Taiwan" by Chu Tsu-yao, Taiwan Weather Bureau, Taipei, Taiwan. Read by the author. With charts.

Symposium ended promptly at 4:33 P.M. after Dr. Hidaka expressed the sentiment of the body that the whole proceedings had been highly successful, for which due appreciation and gratitude were addressed to the organizers of the symposium, as well as to the members who had faithfully attended the sessions.

ABSTRACTS OF PAPERS SUBMITTED

28. "On the Fluctuation of the Kurosiwo and the Oyasiwo" by T. Nan'niti, Meteorological Research Institute, Japan.

29. "A Report on the Oceanographical Observations in the Antarctic Ocean Carried Out on Board the Japanese Whaling Fleet during the Years 1946–1952" by M. Hanzawa and T. Tsuchida, Oceanographical Section, Central Meteorological Observatory, Tokyo, Japan.

ADDITIONAL PAPER SUBMITTED

30. "A New Japanese G.E.K." by K. Suda, Kuroda-Masao, D. Shohji and Sawayanagi-Fumiwo, Hydrographic Division, Maritime Safety Agency, Tokyo, Japan.

A THEORETICAL STUDY ON THE GENERAL CIRCULATION OF THE PACIFIC OCEAN *

By Koji Hidaka **

1. Introduction

The following discussion is one of the results of the research for determining the vertical structure of the wind-driven circulation in an enclosed basin comparable in size to the Pacific Ocean.

The first attempt to verify the effect of prevailing winds in maintaining the oceanic circulation was undertaken by H. U. Sverdrup (1947). According to his result, the oceanic currents in the eastern part of the Equatorial Pacific are largely fed by the energy of the winds blowing over the surface of the ocean. R. O. Reid (1948) also confirmed this conclusion. At nearly the same time Henry Stommel (1948) could explain the intensification of the wind-driven currents along the west coast of an ocean by assuming the existence of horizontal friction and the meridional variation of Coriolis forces. These investigations altogether have enabled us to ascribe the major part of the oceanic circulation to the result of the superincumbent wind system prevailing over the oceans.

Munk (1950) published a very important paper on the wind-driven circulation of the oceans. The next year (1951) he treated the circulation of the North Pacific, regarding this ocean as a triangular basin. He could explain the pattern of the actual ocean circulation very well, so that at the present, there seems to be little room left for us to discuss much more on this subject, so far as the major characteristics of the general circulation in the Pacific Ocean are concerned.

Hidaka (1951) solved the problem of the general circulation which would be produced by both zonal and anticyclonic wind systems. In this computation spherical coordinates were used, thus taking the effect of the sphericity of the earth into account. But both assumptions on the wind distribution gave no essential difference in the results except for the magnitude of mass transport. Moreover, the result for zonal distribution gave no sensible difference in the pattern of the circulation compared with Munk's which was derived by using a rectangular coor-

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dinate system, except in the magnitude of the mass transport. These facts show us that we have only to treat the circulation driven by a zonal wind system.

An earlier paper (Hidaka 1950) contained a theory of ocean circulation using the current velocity in place of the mass transport. The analysis was complex because the vertical variation of the movement of water had to be taken into account. The result was nonetheless quite ridiculous; no perceptible concentration of the streamlines towards the west coast could be found. The explanation for this result was that the approximation to the mass transport was inadequate for its east-west variation. Thus, the solution smoothed out the western currents and boundary vortices which were apparent in Munk's paper.

The mass transport method which has been adopted by Defant (1941), Stockmann (1945–46), Sverdrup (1947), Reid (1948), Munk (1950, 1951) and recently by Walter Hansen (1952) is surely eminent, especially in the point that it enables us to reduce the analysis to two dimensions, and makes the mathematical procedure very simple. Moreover, it is not necessary for us to consider the vertical variation of density and vertical coefficient of eddy viscosity. These authors have indeed contributed greatly to the solution of many important problems on the oceanic circulation by this method. The author himself also employed this method several times in discussing the problems in this direction. However, it is impossible for this method to show how the wind-driven circulation varies in a vertical direction. Neumann also expressed recently (1952) his opinion for the necessity of the dynamical treatment of ocean currents as a three-dimensional problem.

All of these circumstances lead one to recompute the general circulation of the Pacific Ocean under the modified conditions and assumptions. The present investigation is one of the results of the author's efforts in this direction. We here treat the general circulation of the water in a square ocean comparable in size to the entire Pacific Ocean Basin. Spherical coordinates, which were used in a preceding paper (Hidaka 1951), are not used here partly in order to avoid mathematical difficulties. But the more basic reason is that the two systems of coordinates did not give any important difference between Munk's and the author's results except for the magnitude of mass transport. The value of the lateral mixing coefficient is taken 3.08×10^7 c.g.s., a value consistent with the research of former investigators. The wind system is considered zonal, because this assumption is far simpler for the subsequent analysis, and also because there has been found no essential difference between the results obtained under the assumptions of zonal and anticyclonic wind distributions. Of course, the variation of the

Coriolis parameter with latitude is taken into account. The use of current velocity in place of mass transport makes the mathematical analysis many times more complicated because the problem is now three-dimensional. But the result will be of importance because it should give an idea of the vertical structure of the wind-driven circulation of the oceans.

2. Theory

The dynamical equations of the stationary ocean currents, taking both vertical and horizontal mixing into account and neglecting the non-linear terms, are

$$\left.\begin{aligned} A_l \frac{\partial^2 u}{\partial y^2} + \frac{\partial}{\partial z}\left(A_z \frac{\partial u}{\partial z}\right) + 2\omega\rho v \sin\phi - \frac{\partial p}{\partial x} = 0, \\ A_l \frac{\partial^2 v}{\partial x^2} + \frac{\partial}{\partial z}\left(A_z \frac{\partial v}{\partial z}\right) - 2\omega\rho u \sin\phi - \frac{\partial p}{\partial y} = 0, \end{aligned}\right\} \quad (1)$$

where u and v are components of the current velocity in x (eastward positive) and y (northward positive) directions, p is the pressure, ρ the density, A_l and A_z the horizontal and vertical coefficients of eddy viscosity of the water, while ω is the angular velocity of the earth, and ϕ the geographical latitude. The axis of z is taken positive downward, the origin being placed on the undisturbed sea level.

The boundary conditions to be satisfied on the surface ($z = 0$) and at the bottom ($z = h$) are

$$z = 0: \quad -A_z \frac{\partial u}{\partial z} = \tau_x(x,y); \quad -A_z \frac{\partial v}{\partial z} = \tau_y(x,y) \quad (2)$$

and

$$z = h: \quad u = v = 0. \quad (3)$$

Here both coefficients of eddy viscosity A_l and A_z are supposed to be constants. The right members of (2) are known as the wind stresses. The conditions to be satisfied along the coasts are also necessary. These are simply that there is no water flow across and along these coasts. If the coasts consist of vertical cliffs, we have

$$u = v = 0 \text{ at the coast-lines.} \quad (4)$$

In addition to the dynamical equations (1) the equation of continuity should be included. If we neglect the vertical component of velocity, it is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0. \quad (5)$$

The equation (5) assumes that there is neither vertical current nor vertical gradient of the vertical velocity. Thus, our theory cannot be applied to the coastal and other regions of upwelling and sinking caused by local monsoons or other temporary winds. But, if we confine ourselves to the gross features of the horizontal circulation in great

oceans, induced by the superincumbent, quasi-permanent wind system (westerlies or trades), the equation of continuity as given by (5) will not cause serious errors in the results.

There may be some further question concerning the use of (5) for the continuity equation. But, in treating the oceanographic data for estimating geostrophic currents, we always assume

$$\left.\begin{aligned} u &= +\frac{1}{2\omega\rho\sin\phi}\frac{\partial p}{\partial y}; \\ v &= -\frac{1}{2\omega\rho\sin\phi}\frac{\partial p}{\partial x}, \end{aligned}\right\}$$

provided the frictional terms are neglected. These expressions imply that geostrophic currents usually satisfy the equation (5), which shows the absence of horizontal divergence. This means that the equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

may be used without serious errors in treating the general circulation of the oceans.

On eliminating p between the two equations of (1) by cross-differentiation, we have

$$A_l\left(\frac{\partial^3 u}{\partial y^3} - \frac{\partial^3 v}{\partial x^2}\right) + \frac{\partial}{\partial z}\left[A_z\frac{\partial}{\partial z}\left(\frac{\partial u}{\partial y} - \frac{\partial v}{\partial z}\right)\right]$$

$$+ 2\omega\rho\frac{d}{dy}(\sin\phi)\,v = 0 \tag{6}$$

when we take the equation of continuity (5) into account. This equation may also be regarded as expressing the condition that a function p (pressure) should exist on a level z as an exact differential with respect to x and y. And the validity of equation (6) suggests the possibility of determining the pressure in any level z as a function of x and y.

Now suppose the coefficients of mixing A_l and A_z are both independent of z, and put

$$u = \sum_{s=1}^{\infty} u_s(x,y)\cos\frac{(2s-1)\pi z}{2h}, \tag{7}$$

where

$$u_s(x,y) = \frac{2}{h}\int_0^h u(x,y,\zeta)\cos\frac{(2s-1)\pi\zeta}{2h}\,d\zeta \tag{8}$$

and assume, in accord with Stokes,

$$\frac{\partial^2 u}{\partial z^2} = \frac{2}{h}\sum_{s=1}^{\infty}\cos\frac{(2s-1)\pi z}{2h}\int_0^h\frac{\partial^2 u}{\partial\zeta^2}\cos\frac{(2s-1)\pi\zeta}{2h}\,d\zeta; \tag{9}$$

then we have, by substitution from (2), (3) and (8),

$$\frac{2}{h}\int_0^h \frac{\partial^2 u}{\partial \zeta^2}\cos\frac{(2s-1)\pi\zeta}{2h}\,d\zeta = \frac{2}{h}\,\frac{\tau_x(x,y)}{A_z} - \frac{(2s-1)^2\pi^2}{4h^2}\,u_s(x,y)$$

and (9) becomes

$$\frac{\partial^2 u}{\partial z^2} = \sum_{s=1}^{\infty}\left\{\frac{2}{h}\,\frac{\tau_x(x,y)}{A_z} - \frac{(2s-1)^2\pi^2}{4h^2}\,u_s(x,y)\right\}\cos\frac{(2s-1)\pi z}{2h} \tag{10}$$

Similarly we have

$$\frac{\partial^2 v}{\partial z^2} = \sum_{s=1}^{\infty}\left\{\frac{2}{h}\,\frac{\tau_y(x,y)}{A_z} - \frac{(2s-1)^2\pi^2}{4h^2}\,v_s(x,y)\right\}\cos\frac{(2s-1)\pi z}{2h}, \tag{11}$$

where

$$v = \sum_{s=1}^{\infty} v_s(x,y)\cos\frac{(2s-1)\pi z}{2h}. \tag{12}$$

Substitutions of (7), (10), (11) and (12) into (6) and (5) give

$$A_l\left(\frac{\partial^3 u_s}{\partial y^3} - \frac{\partial^3 v_s}{\partial x^3}\right) - \frac{(2s-1)^2\pi^2 A_z}{4h^2}\left(\frac{\partial u_s}{\partial y} - \frac{\partial v_s}{\partial x}\right) + 2\omega\rho\,\frac{\cos\phi}{R}\,v_s + \frac{2}{h}\left(\frac{\partial \tau_x}{\partial y} - \frac{\partial \tau_y}{\partial x}\right) = 0 \tag{13}$$

where R is the radius of the earth, and

$$\frac{\partial u_s}{\partial x} + \frac{\partial v_s}{\partial y} = 0. \tag{14}$$

Equation (14) gives a set of functions $\Psi_s(x,y)$ such that

$$u_s = \frac{\partial \Psi_s}{\partial y}; \quad v_s = -\frac{\partial \Psi_s}{\partial x} \tag{15}$$

and (13) becomes

$$A_l\left(\frac{\partial^4 \Psi_s}{\partial x^4} + \frac{\partial^4 \Psi_s}{\partial y^4}\right) - \frac{(2s-1)^2\pi^2 A_z}{4h^2}\left(\frac{\partial^2 \Psi_s}{\partial x^2} + \frac{\partial^2 \Psi_s}{\partial y^2}\right) - 2\omega\rho\,\frac{\cos\phi}{R}\,\frac{\partial \Psi_s}{\partial x} + \frac{2}{h}\left(\frac{\partial \tau_x}{\partial y} - \frac{\partial \tau_y}{\partial x}\right) = 0 \tag{16}$$

If we introduce two quantities D_l and D_z such that

$$D_l = \pi \sqrt{\frac{A_l}{\rho\omega}} \tag{17}$$

and

$$D_z = \pi \sqrt{\frac{A_z}{\rho\omega}}, \tag{18}$$

equation (16) becomes

$$\frac{D_l^2}{2\pi^2}\left(\frac{\partial^4\Psi_s}{\partial x^4} + \frac{\partial^4\Psi_s}{\partial y^4}\right) - \frac{(2s-1)^2}{8}\left(\frac{D_z}{h}\right)^2\left(\frac{\partial^2\Psi_s}{\partial x^2} + \frac{\partial^2\Psi_s}{\partial y^2}\right) - \frac{\cos\phi}{R}\frac{\partial\Psi_s}{\partial x} + \frac{1}{\rho\omega h}\left(\frac{\partial\tau_x}{\partial y} - \frac{\partial\tau_y}{\partial x}\right) = 0 \tag{19}$$

The quantity D_l may be called "the frictional distance", whereas D_z is the same as Ekman's "depth of frictional influence" except that it does not contain sin ϕ.

The coastal conditions which Ψ_s should satisfy are

$$\Psi_s = \frac{\partial\Psi_s}{\partial n} = 0 \tag{20}$$

along the coast-lines, where $\partial\Psi_s/\partial n$ is the derivative of Ψ_s in the direction normal to the coast-lines.

If equation (19) can be solved and we can determine the functions $\Psi_1(x, y)$, $\Psi_2(x, y)$, $\Psi_3(x, y)$, ..., the sum:

$$\Psi(x, y, z) = \sum_{s=1}^{\infty} \Psi_s(x, y) \cos \frac{(2s-1)\pi z}{2h} \tag{21}$$

will give the horizontal streamlines at any level z for the wind stresses $\tau_x(x, y)$ and $\tau_y(x, y)$. The stream function $\Psi(x, y, z)$ should, of course, satisfy the condition:

$$\Psi = \frac{\partial\Psi}{\partial n} = 0 \tag{22}$$

along the coast-lines and the horizontal streamlines of the currents are given by

$$\Psi(x, y, z) = \text{constant}. \tag{23}$$

3. Infinitely Deep Ocean

If Ψ_s^1 is the solution of (19) when $h = 1$, the solution of (19) will be

$$\Psi_s(x, y) = \frac{1}{h}\Psi_s^1(x, y). \tag{24}$$

Thus we have the solution (21) of our problem in the form:

$$\Psi(x, y, z) = \sum_{s=1}^{\infty} \Psi_s^1(x, y) \frac{1}{h} \cos \frac{(2s-1)\pi z}{2h}, \tag{25}$$

and we may write down (25) in the form:

$$\Psi(x, y, z) = \sum_{s=1}^{\infty} \frac{\Psi_s^1(x, y)}{2D_z} \cos \left\{ \frac{\pi z}{2D_z} (2s-1) \frac{D_z}{h} \right\} \frac{2D_z}{h}.$$

If we consider the depth h of the ocean increases indefinitely, we have

$$(2s-1)\frac{D_z}{h} = \eta, \quad \frac{2D_z}{h} = d\eta \tag{26}$$

and

$$\Psi_s^1(x, y) \rightarrow \Psi_1(x, y; \eta), \tag{27}$$

where $\Psi_1(x, y, \eta)$ is the solution of the equation:

$$\frac{A_l}{2\omega\rho}\left(\frac{\partial^4\Psi_1}{\partial x^4} + \frac{\partial^4\Psi_1}{\partial y^4}\right) - \frac{\eta^2}{8}\left(\frac{\partial^2\Psi_1}{\partial x^2} + \frac{\partial^2\Psi_1}{\partial y^2}\right) - \frac{\cos\phi}{R}\frac{\partial\Psi_1}{\partial x} + \frac{1}{\rho\omega}\left(\frac{\partial\tau_x}{\partial y} - \frac{\partial\tau_y}{\partial x}\right) = 0 \tag{28}$$

which is derived from (19) by putting $(2s-1)\frac{D_z}{h} = \eta$ and $h = 1$.

The right hand sides of the equation (24) will be, when the depth h increases indefinitely,

$$\Psi(x, y, z) = \frac{1}{2D_z}\int_0^{\infty} \Psi_1(x, y; \eta) \cos\left(\frac{\pi z}{2D_z}\eta\right) d\eta. \tag{29}$$

It may be mentioned that η is a parameter increasing from 0 to ∞.

4. Application to the Pacific Ocean

In 1950, Munk used the rectangular coordinates in discussing the wind-driven oceanic circulation in a rectangular ocean. Though he did not take the sphericity of the earth into consideration, he could explain the general pattern of the actual circulation of the Pacific quite well. Further, his result shows little difference from the one above (Hidaka, 1951), in which the curvature of the surface of the earth is taken into account and spherical coordinates are used.

These results show that the Pacific Ocean can be treated approximately as a rectangular ocean, provided we consider the Coriolis para-

meter $2\omega \sin \phi$ varies with y. This is a quite natural consequence when we consider the relation $\phi = \frac{y}{R}$, where R is the mean radius of the earth, and y is counted zero on the equator.

For these reasons, we can represent the Pacific approximately as a square ocean bounded by $x = 0$, $x = a$ and $y = \pm \frac{a}{2}$, in which $y = 0$ coincides with the equator (Fig. 1). Here a is a mean east-west extent of this ocean and approximately equals 120° of longitude or $2\pi/3$ in radians. This means that the northern and southern boundaries of this ocean are given by $y = \pm \frac{2\pi R}{3}$ or the parallels of 60° N and S.

To solve the equation (28), assume

$$\Psi_1(x, y; \eta) = \sum_m M_m(y) \; N_m(x; \eta), \tag{30}$$

where $m = 1, 2, 3, \ldots$ and $N_m(x, \eta)$ are functions of x which are to be determined later, while $M_m(y)$ are of the forms:

$$\begin{aligned} M_m(y) &= \cos \frac{\pi y}{2a} \cos \frac{m\pi y}{2a} \quad \text{for } m\text{: odd} \\ &= \cos \frac{\pi y}{2a} \sin \frac{m\pi y}{2a} \quad \text{for } m\text{: even.} \end{aligned} \tag{31}$$

Since these functions and their y-derivatives vanish along $y = \pm \frac{a}{2}$, (30) and its y-derivatives will also vanish along $y = \pm \frac{a}{2}$. This makes the function $\Psi(x, y, z)$ satisfy the condition (22) along the northern and southern boundaries $y = \pm \frac{a}{2}$.

5. Stresses of Winds over the Pacific Ocean

Dr. Munk kindly furnished me with his unpublished data of the distribution of the wind-stresses over the Pacific Ocean north of 5° S. From these data, the most probable distribution of the wind-stresses was found to be zonal and determined as

$$\begin{aligned} \tau_x(\phi) = &+ 0.045544 M_1'(\phi) - 0.262308 M_2'(\phi) \\ &+ 0.022902 M_3'(\phi) + 0.069493 M_4'(\phi) \\ &- 0.036900 M_5'(\phi) + 0.011560 M_6'(\phi) \text{ dyne/cm}^2 \end{aligned} \tag{32}$$

where ϕ is latitude so that $\phi = y/R$ and $M_m'(\phi)$ stand for

$$\frac{d}{d\phi} M_m(\phi) = R \frac{d}{dy} M_m(\phi).$$

If we are to derive (32) from a stress-function $T(x, y)$ such that

$$\tau_x = \frac{\partial T}{\partial y}; \quad \tau_y = -\frac{\partial T}{\partial x}, \tag{33}$$

we have a stress function which depends on ϕ or y only, or

$$\begin{aligned} T(\phi) &= \sum_{m=1}^{\infty} T_m \cdot M_m(\phi) \\ &= [0.29003M_1(\phi) - 1.67122M_2(\phi) \\ &\quad + 0.14591M_3(\phi) + 0.44276M_4(\phi) \\ &\quad - 0.23510M_5(\phi) + 0.07388M_6(\phi)] \times 10^8 \text{ dynes/cm}, \end{aligned} \tag{34}$$

provided we take $R = 6.3712 \times 10^8$ cm.

The values of stress and stress function computed after the formulas (32) and (34) are compiled in Table I and illustrated in Figure 2.

From the formula (32) we have a much larger wind stress in the west wind belt in the South Pacific Ocean than in the North Pacific. It is not because we had wind observations available from the former, but is a necessary consequence resulting from determining the formula so as to meet the observational data for the latitudes north of 5° S. As a matter of fact, the west wind belt in the South Pacific is said to have stronger wind than that of the North Pacific. So this formula will not give wind stresses in the South Pacific too inconsistent with observations.

6. Elimination of y-Coordinate

The equation to be solved is from (28)

$$\frac{D_l^2}{2\pi^2}\left(\frac{\partial^4\Psi_1}{\partial x^4} + \frac{\partial^4\Psi_1}{\partial y^4}\right) - \frac{\eta^2}{8}\left(\frac{\partial^2\Psi_1}{\partial x^2} + \frac{\partial^2\Psi_1}{\partial y^2}\right) - \frac{\cos\phi}{R}\frac{\partial\Psi_1}{\partial x} + \frac{2}{\rho\omega}\left(\frac{\partial\tau_x}{\partial y} - \frac{\partial\tau_y}{\partial x}\right) = 0. \tag{35}$$

where

$$D_l = \pi\sqrt{\frac{A_l}{\rho\omega}}. \tag{36}$$

Between the equator and 60° N or S, $\cos\phi$ varies from 1 to ½. Since this is not a large variation, we may take the average value for $\cos\phi$ for this range, or

$$\overline{\cos\phi} = \frac{1}{2\pi/3}\int_{-\frac{\pi}{3}}^{+\frac{\pi}{3}} \cos\phi\, d\phi = \frac{3\sqrt{3}}{2\pi}.$$

TABLE I

Assumed Meridional Variation of the Wind Stress τ and Stress Function T

y/a	Lat.	T (dynes/cm)	τ (dyne/cm²)	Remarks	y/a	Lat.	T (dynes/cm)	τ (dyne/cm²)	Remarks
+.500	60° N	.000	.000		0.000	0°	+ .201 × 10^8	−.272	
+.475	57° N	− .037 × 10^8	.211	West	−0.025	3° S	.304 × 10^8	−.360	S.E.
+.450	54° N	− .141 × 10^8	.396		−0.050	6° S	.441 × 10^8	−.463	
+.425	51° N	− .301 × 10^8	.528	Wind	−0.075	9° S	.663 × 10^8	−.554	Trades
+.400	48° N	− .493 × 10^8	.589		−0.100	12° S	.811 × 10^8	−.606	
+.375	45° N	− .694 × 10^8	.573	Drift	−0.125	15° S	1.018 × 10^8	−.595	
+.350	42° N	− .876 × 10^8	.482		−0.150	18° S	1.208 × 10^8	−.514	
+.325	39° N	−1.015 × 10^8	.327		−0.175	21° S	1.360 × 10^8	−.369	
+.300	36° N	−1.094 × 10^8	.132		−0.200	24° S	1.454 × 10^8	−.174	
+.275	33° N	−1.104 × 10^8	−.075		−0.225	27° S	1.476 × 10^8	+.045	
+.250	30° N	−1.044 × 10^8	−.266		−0.250	30° S	1.424 × 10^8	+.259	
+.225	27° N	− .926 × 10^8	−.416	N.E.	−0.275	33° S	1.303 × 10^8	+.438	West
+.200	24° N	− .767 × 10^8	−.507		−0.300	36° S	1.131 × 10^8	+.564	
+.175	21° N	− .588 × 10^8	−.534	Trade	−0.325	39° S	.927 × 10^8	+.626	Wind
+.150	18° N	− .411 × 10^8	−.502		−0.350	42° S	.714 × 10^8	+.626	
+.125	15° N	− .253 × 10^8	−.431		−0.375	45° S	.510 × 10^8	+.574	Drift
+.100	12° N	− .123 × 10^8	−.343		−0.400	48° S	.331 × 10^8	+.484	
+.075	9° N	− .024 × 10^8	−.264		−0.425	51° S	.187 × 10^8	+.371	
+.050	6° N	+ .053 × 10^8	−.219	Doldrum	−0.450	54° S	.083 × 10^8	+.249	
+.025	3° N	+ .122 × 10^8	−.219		−0.475	57° S	.021 × 10^8	+.124	
+.000	0°	+ .201 × 10^8	−.272		−.500	60° S	.000 × 10^8	.000	

Thus the third term in (35) now becomes approximately

$$-\frac{\cos\phi}{R}\frac{\partial\Psi_1}{\partial x} = -\frac{3\sqrt{3}}{2\pi R}\frac{\partial\Psi_1}{\partial x}. \tag{37}$$

Substituting (30), (32), (34) and (37) in (35), we have

$$\sum_m \left[\frac{D_l^2}{2\pi^2}\left\{\frac{1}{\left(\frac{2\pi}{3}\right)^4 R^4}\frac{d^4N_m}{d\lambda^4}M_m(\phi) + N_m(\lambda;\eta)\frac{1}{R^4}\frac{d^4N_m}{d\phi^4}\right\}\right.$$

$$-\frac{\eta^2}{8}\left\{\frac{1}{\left(\frac{2\pi}{3}\right)^2 R^2}\frac{d^2N_m}{d\lambda^2}M_m(\phi) + N_m(\lambda;\eta)\frac{1}{R^2}\frac{d^2N_m}{d\phi^2}\right\}$$

$$+ N_m(\lambda;\eta)\frac{1}{R^2}\frac{d^2M_m}{d\phi^2}$$

$$\left.-\frac{\frac{3\sqrt{3}}{2\pi}}{\frac{2\pi}{3}R^2}\frac{dN_m}{d\lambda}M_m(\phi)\right] - \frac{1}{\rho\omega}\frac{1}{R^2}\sum_m T_m\frac{d^2M_m}{d\phi^2} = 0 \tag{38}$$

where we have

$$\lambda = \frac{x}{(2\pi R/3)}, \tag{39}$$

so that the ocean is supposed to be bounded by the meridians of 0° and 120°, and the western and eastern boundaries are given by $\lambda = 0$ and $\lambda = 1$ respectively.

Now it is possible to express $\frac{d^2M_m}{dy^2}$ and $\frac{d^4M_m}{dy^4}$ in terms of $M_m(\phi)$, or

$$\frac{d^2M_m}{dy^2} = \sum_i \alpha_i^m M_i(\phi)$$

and

$$\frac{d^4M_m}{dy^4} = \sum_i \beta_i^m M_i(\phi). \tag{40}$$

Substituting (40) in (38) we have

$$\sum_m M_m(\phi)\left\{\frac{D_l^2}{2\pi^2}\frac{81}{16\pi^4R^4}\frac{d^4N_m}{d\lambda^4} - \frac{\eta^2}{8}\frac{9}{4\pi^2R^2}\frac{d^2N_m}{dy^2}\right.$$

$$-\frac{\frac{3\sqrt{3}}{2\pi}}{\frac{2\pi}{3}R^2}\frac{dN_m}{d\lambda} + \sum_i\left(-\frac{\eta^2}{8}\frac{1}{R^2}\alpha_m^i + \frac{D_l^2}{2\pi^2}\frac{1}{R^4}\beta_m^i\right)N_i$$

$$\left.+\frac{1}{\rho\omega}\frac{1}{R^2}\sum\alpha_m^i T_i\right\} = 0. \tag{41}$$

In order that this relation should be always valid, the coefficients of $M_m(\phi)$ must vanish. Thus we have

$$\frac{81}{32}\frac{D_l^2}{R^2}\frac{d^4N_m}{d\lambda^4} - \frac{9}{32\pi^2}\eta^2\frac{d^2N_m}{d\lambda^2} - \frac{9\sqrt{3}}{4\pi^2}\frac{dN_m}{d\lambda} + \sum_i\left(-\frac{1}{8}\alpha_m^i\eta^2 + \frac{1}{2\pi^2}\beta_m^i\frac{D_l^2}{R^2}\right)N_i + \frac{1}{\rho\omega}\sum_i\alpha_m^iT_i = 0 \quad (42)$$

where T_i is given by (34).

It may be anticipated from (39) and (40) that the values of β_m^i are larger than that of α_m^i for any corresponding set of values of i and m. But the ratio

$$\frac{D_l^2}{R^2} = \frac{\pi^2}{\rho\omega}\frac{A_l}{R^2}$$

is of the order of 10^{-4} for the usual value of A_l $(=10^8)$, so that we may neglect the terms of β_m^i in the coefficients of N_i in (42). Then (42) becomes

$$\frac{81}{32}\frac{D_l^2}{R^2}\frac{d^4N_m}{d\lambda^4} - \frac{9}{32\pi^2}\eta^2\frac{d^2N_m}{d\lambda^2} - \frac{9\sqrt{3}}{4\pi^2}\frac{dN_m}{d\lambda} - \frac{\eta^2}{8}\sum_i\alpha_m^iN_i + \frac{1}{\rho\omega}\sum_i\alpha_m^iT_i = 0. \quad (43)$$

7. Determination of the Values of α_m^i

The coefficients of $M_m(\phi)$ in the expansions of $\frac{d^2M_m}{d\phi^2}$ were evaluated as far as $M_{10}(\phi)$, the higher terms being neglected.

For the ocean under consideration, we have

$$\left.\begin{aligned}
M_1''(\phi) &= -\frac{9}{11}\{M_1(\phi) + 8M_3(\phi) - 6M_5(\phi) + 4M_7(\phi) - 2M_9(\phi)\},\\
M_3''(\phi) &= -\frac{9}{11}\{-3M_1(\phi) + 20M_2(\phi) + 18M_5(\phi) - 12M_7(\phi) + 6M_9(\phi)\},\\
M_5''(\phi) &= -\frac{9}{11}\{+5M_1(\phi) - 15M_3(\phi) + 69M_5(\phi) + 20M_7(\phi) - 10M_9(\phi)\},\\
M_7''(\phi) &= -\frac{9}{11}\{-7M_1(\phi) + 21M_3(\phi) - 35M_5(\phi) + 148M_7(\phi) + 14M_9(\phi)\},\\
M_9''(\phi) &= -\frac{9}{11}\{+9M_1(\phi) - 27M_3(\phi) + 45M_5(\phi) - 63M_7(\phi) + 257M_9(\phi)\},
\end{aligned}\right\} \quad (44)$$

and

$$M_2''(\phi) = -\frac{3}{4}\{7M_2(\phi) + 16M_4(\phi) - 12M_6(\phi) + 8M_8(\phi) - 4M_{10}(\phi)\},$$

$$M_4''(\phi) = -\frac{3}{4}\left\{\begin{array}{l} -8M_2(\phi) + 43M_4(\phi) + 24M_6(\phi) \\ \qquad -16M_8(\phi) + 8M_{10}(\phi) \end{array}\right\},$$

$$M_6''(\phi) = -\frac{3}{4}\left\{\begin{array}{l} +12M_2(\phi) - 24M_4(\phi) + 111M_6(\phi) \\ \qquad +24M_8(\phi) - 12M_{10}(\phi) \end{array}\right\},$$

$$M_8''(\phi) = -\frac{3}{4}\left\{\begin{array}{l} -16M_2(\phi) + 32M_4(\phi) - 48M_6(\phi) \\ \qquad +211M_8(\phi) + 16M_{10}(\phi) \end{array}\right\},$$

$$M_{10}''(\phi) = -\frac{3}{4}\left\{\begin{array}{l} 20M_2(\phi) - 40M_4(\phi) + 60M_6(\phi) \\ \qquad -80M_8(\phi) + 343M_{10}(\phi) \end{array}\right\}, \tag{45}$$

Substituting (44) and (45) into equation (43), and evaluating the numerical values of their coefficients with $R = 6.3712 \times 10^8$ cm, $\rho\omega = 0.000075$ sec^{-1} and

$$A_l = 3.08 \times 10^7 \text{ c.g.s.}, \tag{46}$$

we have for odd series

$$\begin{aligned}
&D(N_1) + 4747600\eta^2 \times \frac{9}{11}(N_1 - 3N_3 + 5N_5 - 7N_7 + 9N_9) - 0.548249 \times 10^{20} = 0,\\
&D(N_3) + 4747600\eta^2 \times \frac{9}{11}(8N_1 + 20N_3 - 15N_5 + 21N_7 - 27N_9) - 3.63163 \times 10^{20} = 0,\\
&D(N_5) + 4747600\eta^2 \times \frac{9}{11}(-6N_1 + 18N_3 + 69N_5 - 35N_7 + 45N_9) + 6.35413 \times 10^{20} = 0,\\
&D(N_7) + 4747600\eta^2 \times \frac{9}{11}(+4N_1 - 12N_3 + 20N_5 + 148N_7 - 63N_9) + 2.19300 \times 10^{20} = 0,\\
&D(N_9) + 4747600\eta^2 \times \frac{9}{11}(-2N_1 + 6N_3 - 10N_5 + 14N_7 + 257N_9) - 1.096499 \times 10^{20} = 0,
\end{aligned} \tag{47}$$

where the operator D stands for

$$D = \frac{d^4}{d\lambda^4} - 1082323\eta^2\frac{d^2}{d\lambda^2} - 14997110\frac{d}{d\lambda}. \tag{48}$$

For even series, we have

$$\begin{aligned}
&D(N_2) + 4747600\eta^2 \times -\frac{3}{4}(+7N_2 - 8N_4 + 12N_6 - 16N_8 + 20N_{10}) + 5.45179 \times 10^{20} = 0,\\
&D(N_4) + 4747600\eta^2 \times \frac{3}{4}(+16N_2 + 43N_4 - 24N_6 + 32N_8 - 40N_{10}) + 3.59829 \times 10^{20} = 0,\\
&D(N_6) + 4747600\eta^2 \times \frac{3}{4}(-12N_2 + 24N_4 + 111N_6 - 48N_8 + 60N_{10}) - 14.76753 \times 10^{20} = 0,\\
&D(N_8) + 4747600\eta^2 \times \frac{3}{4}(+8N_2 - 16N_4 + 24N_6 + 211N_8 - 80N_{10}) + 7.09512 \times 10^{20} = 0,\\
&D(N_{10}) + 4747600\eta^2 \times -\frac{3}{4}(-4N_2 + 8N_4 - 12N_6 + 16N_8 + 343N_{10}) - 3.54756 \times 10^{20} = 0,
\end{aligned} \tag{49}$$

where the operator D is also given by (48).

To solve the simultaneous differential equations (47) and (48), we employ the method of indeterminate multipliers. Let the odd set of equations be of the forms:

$$\begin{aligned}
&D(N_1) + \sum_{i=1}^{9} C_i^1 N_i + E_1 = 0,\\
&D(N_3) + \sum_{i=1}^{9} C_i^3 N_i + E_3 = 0,\\
&D(N_5) + \sum_{i=1}^{9} C_i^5 N_i + E_5 = 0,\\
&D(N_7) + \sum_{i=1}^{9} C_i^7 N_i + E_7 = 0,\\
&D(N_9) + \sum_{i=1}^{9} C_i^9 N_i + E_9 = 0,
\end{aligned} \tag{50}$$

where the summation is made with respect to odd numbers.

Multiply each of the five equations in (50) by l_1, l_3, l_5, l_7, and l_9 respectively, and add together; we have then

$$\begin{aligned}
&D(l_1N_1 + l_3N_3 + l_5N_5 + l_7N_7 + l_9N_9)\\
&\quad + (C_1^1 l_1 + C_1^3 l_3 + C_1^5 l_5 + C_1^7 l_7 + C_1^9 l_9) N_1\\
&\quad + (C_3^1 l_1 + C_3^3 l_3 + C_3^5 l_5 + C_3^7 l_7 + C_3^9 l_9) N_3\\
&\quad + (C_5^1 l_1 + C_5^3 l_3 + C_5^5 l_5 + C_5^7 l_7 + C_5^9 l_9) N_5\\
&\quad + (C_7^1 l_1 + C_7^3 l_3 + C_7^5 l_5 + C_7^7 l_7 + C_7^9 l_9) N_7\\
&\quad + (C_9^1 l_1 + C_9^3 l_3 + C_9^5 l_5 + C_9^7 l_7 + C_9^9 l_9) N_9\\
&\quad + (l_1E_1 + l_3E_3 + l_5E_5 + l_7E_7 + l_9E_9) = 0
\end{aligned} \tag{51}$$

Now let

$$\begin{aligned}
C_1^1 l_1 + C_1^3 l_3 + C_1^5 l_5 + C_1^7 l_7 + C_1^9 l_9 &= l_1\xi,\\
C_3^1 l_1 + C_3^3 l_3 + C_3^5 l_5 + C_3^7 l_7 + C_3^9 l_9 &= l_3\xi,\\
&\cdots\cdots\cdots\cdots,\\
C_9^1 l_1 + C_9^3 l_3 + C_9^5 l_5 + C_9^7 l_7 + C_9^9 l_9 &= l_9\xi,
\end{aligned} \tag{52}$$

and eliminate l_1, l_3, . . ., l_9; we have then

$$\begin{vmatrix}
C_1^1 - \xi & C_1^3 & C_1^5 & C_1^7 & C_1^9\\
C_3^1 & C_3^3 - \xi & C_3^5 & C_3^7 & C_3^9\\
C_5^1 & C_5^3 & C_5^5 - \xi & C_5^7 & C_5^9\\
C_7^1 & C_7^3 & C_7^5 & C_7^7 - \xi & C_7^9\\
C_9^1 & C_9^3 & C_9^5 & C_9^7 & C_9^9 - \xi
\end{vmatrix} = 0. \tag{53}$$

This equation has five real roots. Let them be

$$\xi_1,\ \xi_3,\ \xi_5,\ \xi_7 \text{ and } \xi_9$$

and, corresponding to them, equations (52 will give five sets of l_1, l_3, . . ., l_9, or

$$\begin{aligned}
&\xi_1 : l_1^1,\ l_3^1,\ l_5^1,\ l_7^1,\ l_9^1;\\
&\xi_3 : l_1^3,\ l_3^3,\ l_5^3,\ l_7^3,\ l_9^3;\\
&\xi_5 : l_1^5,\ l_3^5,\ l_5^5,\ l_7^5,\ l_9^5;\\
&\xi_7 : l_1^7,\ l_3^7,\ l_5^7,\ l_7^7,\ l_9^7;\\
&\xi_9 : l_1^9,\ l_3^9,\ l_5^9,\ l_7^9,\ l_9^9.
\end{aligned} \tag{54}$$

These five sets of roots and multipliers l's will give Y_m and F_m as

$$\begin{aligned}
Y_m &= l_1^m N_1 + l_3^m N_3 + l_5^m N_5 + l_7^m N_7 + l_9^m N_9;\\
F_m &= l_1^m E_1 + l_3^m E_3 + l_5^m E_5 + l_7^m E_7 + l_9^m E_9\\
&\quad (m = 1, 3, 5, 7, 9)
\end{aligned} \tag{55}$$

and the corresponding five equations

$$\begin{aligned}
&D(Y_m) + \xi_m Y_m + E_m = 0\\
&\quad (m = 1, 3, 5, 7, 9)
\end{aligned} \tag{56}$$

for Y_1, Y_3, . . ., Y_9. They are no longer simultaneous, and not difficult to solve. The same, of course, applies to even sets, too.

Practically, the equation corresponding to (53) is

$$\begin{vmatrix}
1-\zeta & +8 & -6 & +4 & -2\\
-3 & 20-\zeta & +18 & -12 & +6\\
+5 & -15 & 69-\zeta & +20 & -10\\
-7 & +21 & -35 & 148-\zeta & +14\\
+9 & -27 & +45 & -63 & 257-\zeta
\end{vmatrix} = 0$$

or

$$\begin{aligned}
&210830400 - 84156468\zeta + 4625225\zeta^2 - 78771\zeta^3\\
&\quad + 495\zeta^4 - \zeta^5 = 0
\end{aligned} \tag{57}$$

where

$$\zeta = \xi/(4.38649084 \times 9/11) \tag{58}$$

and the five roots of (57) are

$$\begin{aligned}
\zeta_1 &= 2.9641943,\\
\zeta_3 &= 26.7072817,\\
\zeta_5 &= 74.3718483,\\
\zeta_7 &= 146.456904,\\
\zeta_9 &= 244.499771.
\end{aligned} \tag{59}$$

For even series we have, corresponding to (57), (58) and (59),

$$\begin{vmatrix}
7-\gamma & +16 & -12 & +8 & -4\\
-8 & 43-\gamma & +24 & -16 & +8\\
+12 & -24 & 111-\gamma & +24 & -12\\
-16 & +32 & -48 & 211-\gamma & +16\\
+20 & -40 & +60 & -80 & 343-\gamma
\end{vmatrix} = 0$$

or

$$5217079023 - 593115237\gamma + 16671798\gamma^2 - 172458\gamma^3 + 715\gamma^4 - \gamma^5 = 0 \tag{60}$$

where

$$\gamma = \xi/(4.38649084 \times 3/4) \tag{61}$$

and

$$\begin{aligned} \gamma_2 &= 12.8567852, \\ \gamma_4 &= 51.494636, \\ \gamma_6 &= 116.1536052, \\ \gamma_8 &= 207.4231320, \\ \gamma_{10} &= 327.071842. \end{aligned} \tag{62}$$

8. Differential Equations for *Y's* and their Solutions

From the numerical computations described above, the numerical coefficients of the differential equations for $Y_m(\lambda; \eta)$ were determined as follows:

$$\begin{aligned} D(Y_1) &+ 11514116\eta^2 Y_1 - 0.4037686 \times 10^{20} = 0, \\ D(Y_3) &+ 103741765\eta^2 Y_3 - 6.3254121 \times 10^{20} = 0, \\ D(Y_5) &+ 288890008\eta^2 Y_5 - 204.1449265 \times 10^{20} = 0, \\ D(Y_7) &+ 568897198\eta^2 Y_7 + 311.4127463 \times 10^{20} = 0, \\ D(Y_9) &+ 949734910\eta^2 Y_9 + 257.7413034 \times 10^{20} = 0. \end{aligned} \tag{63}$$

and

$$\begin{aligned} D(Y_2) &+ 51883042\eta^2 Y_2 + 7.4929828 \times 10^{20} = 0, \\ D(Y_4) &+ 207804544\eta^2 Y_4 - 5.3393918 \times 10^{20} = 0, \\ D(Y_6) &+ 468733228\eta^2 Y_6 + 258.843806 \times 10^{20} = 0, \\ D(Y_8) &+ 837047752\eta^2 Y_8 + 158.8661390 \times 10^{20} = 0, \\ D(Y_{10}) &+ 1319885336\eta^2 Y_{10} + 290.043938 \times 10^{20} = 0. \end{aligned} \tag{64}$$

where

$$D = \frac{d^4}{d\lambda^4} - 1082323\eta^2 \frac{d^2}{d\lambda^2} - 14997110 \frac{d}{d\lambda}$$

and $Y_1, Y_3, \ldots, Y_9$; $Y_2, Y_4, \ldots, Y_{10}$ stand for the following expressions in terms of N_m:

$$\begin{aligned} Y_1 &= N_1 + 0.2167031N_3 - 0.0302211N_5 + 0.0100338N_7 \\ &\quad - 0.0045539N_9; \\ Y_3 &= N_1 + 4.6332707N_3 + 1.6778105N_5 - 0.2720794N_7 \\ &\quad + 0.1018516N_9; \\ Y_5 &= N_1 - 7.3461297N_3 - 31.5044500N_5 - 13.1812666N_7 \\ &\quad + 2.0803739N_9, \\ Y_7 &= N_1 - 4.2883468N_3 + 20.4004807N_5 + 99.0498144N_7 \\ &\quad + 47.0163475N_9, \\ Y_9 &= N_1 - 3.6583547N_3 + 9.7849522N_5 - 40.0969663N_7 \\ &\quad - 245.9320935N_9. \end{aligned} \tag{65}$$

and

$$\begin{aligned}
Y_2 &= N_2 + 0.3172231N_4 - 0.0501698N_6 + 0.0180624N_8 \\
&\quad - 0.0086497N_{10}, \\
Y_4 &= N_2 + 4.1262613N_4 + 1.5874177N_6 - 0.2597861N_8 \\
&\quad + 0.0995609N_{10}, \\
Y_6 &= N_2 - 5.4990870N_4 - 23.8405548N_6 - 10.3129949N_8 \\
&\quad + 1.6109253N_{10}, \\
Y_8 &= N_2 - 3.0874234N_4 + 13.8285447N_6 + 68.6295877N_8 \\
&\quad + 33.3180647N_{10}, \\
Y_{10} &= N_2 - 2.5712654N_4 + 6.4271377N_6 - 25.6939046N_8 \\
&\quad - 160.9722444N_{10}. \qquad (66)
\end{aligned}$$

If the 10 functions $Y_1, Y_2, \ldots, Y_{10}$ can be determined by solving the differential equations (63) and (64), it will be possible to compute $N_1(\lambda; \eta), N_2(\lambda; \eta), \ldots, N_{10}(\lambda; \eta)$ from the following expressions which are the reversions of the expressions (65) and (66).

$$\begin{aligned}
N_1 &= + 1.0650221Y_1 - 0.05878696Y_3 - 0.00491292Y_5 \\
&\quad - 0.001038174Y_7 - 0.000284101Y_9, \\
N_3 &= - 0.2793058Y_1 + 0.2586992\ Y_3 + 0.01644431Y_5 \\
&\quad + 0.003283144Y_7 + 0.000879072Y_9, \\
N_5 &= + 0.1254434Y_1 - 0.07711532Y_3 - 0.04050495Y_5 \\
&\quad - 0.006251173Y_7 - 0.001571970Y_9, \\
N_7 &= - 0.05969848Y_1 + 0.03367969Y_3 + 0.01083299Y_5 \\
&\quad + 0.01265900Y_7 + 0.002526788Y_9, \\
N_9 &= + 0.02320969Y_1 - 0.01264167Y_3 - 0.003642393Y_5 \\
&\quad - 0.002365708Y_7 - 0.004554906Y_9. \qquad (67)
\end{aligned}$$

and

$$\begin{aligned}
N_2 &= + 1.1172140Y_2 - 0.1028957Y_4 - 0.0109283Y_6 \\
&\quad - 0.0026156Y_8 - 0.0007745Y_{10}, \\
N_4 &= - 0.3385977Y_2 + 0.3066091Y_4 + 0.0247985Y_6 \\
&\quad + 0.0055792Y_8 + 0.0016107Y_{10}, \\
N_6 &= + 0.1613919Y_2 - 0.0943220Y_4 - 0.0548464Y_6 \\
&\quad - 0.0096171Y_8 - 0.0026064Y_{10}, \\
N_8 &= - 0.0792995Y_2 + 0.0420747Y_4 + 0.0147581Y_6 \\
&\quad + 0.0184664Y_8 + 0.0040001Y_{10}, \\
N_{10} &= + 0.0314504Y_2 - 0.0160186Y_4 - 0.0050095Y_6 \\
&\quad - 0.0034369Y_8 - 0.0069853Y_{10}. \qquad (68)
\end{aligned}$$

Substituting the functions $N_1(x; \eta), N_2(x; \eta), \ldots, N_{10}(x; \eta)$ thus obtained in (30), we shall obtain the expression for $\Psi_1(x, y; \eta)$. Further substitution in (29) will give the solution of the problem as

$$\Psi(x, y, z) = \frac{1}{2D_z} \cdot \sum_m M_m(y) \int_0^\infty N_m(x; \eta) \cos\left(\frac{\pi z}{2D_z}\eta\right) d\eta. \qquad (69)$$

The method of solving equations (63) and (64) and the evaluation of the integral:

$$\int_0^\infty N_m(x;\eta)\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta$$

will be discussed in the following section.

9. Integration of the Differential Equations

The next step will be to solve the ten differential equations (63) and (64). Let any one of these equations be

$$\frac{d^4Y}{d\lambda^4} - 1082323\eta^2\frac{d^2Y}{d\lambda^2} - 14997110\frac{dY}{d\lambda} + b\eta^2Y + c = 0 \qquad (70)$$

where b and c are constants assigned to each of these ten equations. Since a particular solution of this equation is

$$Y_p = -\frac{c/b}{\eta^2}, \qquad (71)$$

the general integral of (70) will be of the form:

$$Y(\lambda) = Ae^{\alpha\lambda} + Be^{\beta\lambda} + Ce^{\gamma\lambda} + De^{\delta\lambda} - \frac{c/b}{\eta^2} \qquad (72)$$

where α, β, γ and δ are the four roots of the algebraic equation:

$$\sigma^4 - 1082323\eta^2\sigma^2 - 14997110\sigma + b\eta^2 = 0 \qquad (73)$$

and A, B, C, D are constants to be determined according to the conditions:

$$Y(0) = Y(1) = 0;$$
$$Y'(0) = Y'(1) = 0. \qquad (74)$$

The equation (73) has four roots α, β, γ and δ for any given value of η, and A, B, C and D all depend upon α, β, γ and δ.

The parameter η varies from 0 to ∞, and the values of α, β, γ, δ all depend upon η. When η is very large, these four roots are approximately

$$\alpha = +1040.3075\eta,$$
$$\beta = -1040.3075\eta,$$
$$\gamma = +(b/1082323)^{1/2},$$
$$\delta = -(b/1082323)^{1/2}. \qquad (75)$$

As η decreases, α, β, γ and δ also change gradually. For η less than a certain value between $\eta = 0.4$ and $\eta = 0.3$, β and δ become complex conjugate. As η approaches 0, α, β and δ approach finite values, while γ decreases indefinitely as $\infty\eta^2$. Thus we have, when $\eta \to 0$.

$$\alpha = 2p,$$
$$\beta = -p + iq,$$
$$\gamma = b\eta^2/8p^3,$$
$$\delta = -p - iq. \qquad (76)$$

where

$$p = (14997110)^{1/3},$$
$$q = \frac{\sqrt{3}}{2}p. \tag{77}$$

For the intermediate value of η, these four roots vary continuously except β and δ which change from complex conjugates to real as η increases from $\eta = 0.3$ to $\eta = 0.4$.

Of course, there are 10 series of such four roots of 10 equations (70), each varying with the parameter η.

The constants A, B, C and D can be, of course, expressed in terms of α, β, γ and δ. Thus the solution Y becomes, when β and δ are complex conjugates of the form

$$\beta = +p + qi; \qquad \delta = p - qi. \tag{78}$$

$$Y = \left\{ 1 + \frac{\gamma}{\alpha-\gamma}e^{\alpha(\lambda-1)} - \frac{\alpha}{\alpha-\gamma}e^{\gamma(\lambda-1)} + \left(\frac{\alpha}{\alpha-\gamma}e^{-\gamma} - 1\right)e^{-p\lambda}\cos q\lambda + \left(\frac{\alpha}{\alpha-\gamma}e^{-\gamma}\frac{p+\gamma}{q} - \frac{p}{q}\right)e^{-p\lambda}\sin q\lambda \right\} Y_p \tag{79}$$

and, when α, β, γ, δ are all real,

$$Y = \left[1 + \frac{\gamma}{\alpha-\gamma}e^{\alpha(\lambda-1)} + \left\{ \frac{\delta}{\beta-\delta} + \frac{\alpha}{\alpha-\gamma}\frac{\gamma-\delta}{\beta-\delta}e^{-\gamma} \right\} e^{\beta\lambda} - \frac{\alpha}{\alpha-\gamma}e^{\gamma(\lambda-1)} + \left\{ -\frac{\beta}{\beta-\delta} + \frac{\alpha}{\alpha-\gamma}\frac{\beta-\gamma}{\beta-\delta}e^{-\gamma} \right\} e^{\delta\lambda} \right] Y_p \tag{80}$$

where Y_p is the particular solution given by (71), of the equation (70).

When η increases γ also increases. If we can neglect $e^{-\gamma}$, the expression (80) will be further simplified, and we have

$$Y = \left\{ 1 + \frac{\gamma}{\alpha-\gamma}e^{\alpha(\lambda-1)} + \frac{\delta}{\beta-\delta}e^{\beta\lambda} - \frac{\alpha}{\alpha-\gamma}e^{\gamma(\lambda-1)} - \frac{\beta}{\beta-\delta}e^{\delta\lambda} \right\} Y_p. \tag{81}$$

Since Y_p is given by (71) as

$$Y_p = -\frac{(b/c)}{\eta^2}$$

the solutions of the equations (63) and (64) will tend to zero as η increases indefinitely.

The values of the roots α, β, γ and δ of each of the 10 equations given by (63) and (64) were computed numerically and given in Tables V–XIV.

10. Computation of the Currents

In order to calculate the distribution of the currents at various levels, we had first to compute $Y_1(\lambda;\eta)$, $Y_2(\lambda;\eta)$, . . ., $Y_{10}(\lambda;\eta)$ according to one of the expressions (79), (80) and (81) for

$\lambda = 0.0000, 0.0025, 0.0050, \ldots, 0.0500, 0.0550, 0.0600, \ldots,$
$0.1000, 0.1100, 0.1200, 0.1300, \ldots, 0.2000$

and for

$\eta = 0.0, 0.1, 0.2, \ldots, 1.0, 2.0, 3.0, \ldots, 10.0.$

For larger values of η, we have

$$\begin{aligned} \alpha &= +\ 1040.3075\eta, \\ \beta &= -\ 1040.3075\eta, \\ \gamma &= +\ (b/1082323)^{1/2}, \\ \delta &= -\ (b/1082323)^{1/2} \end{aligned} \tag{82}$$

very accurately, while $Y_p(\eta)$ are all very small, so that $Y_2(\lambda;\eta)$ will be approximately given by

$$Y = \left\{ 1 - e^{\gamma(\lambda-1)} - e^{-\gamma\lambda} \right\} \frac{(c/b)}{\eta^2} \tag{83}$$

where γ, and c are independent of η. It will be more convenient to leave (83) as it stands rather than to compute their values against η.

These values of the ten functions $Y_m(\lambda;\eta)$ may be then converted into the functions $N_m(\lambda;\eta)$ by virtue of the formulas (67) and (68).

Substitutions of the functions $N_1(\lambda;\eta)$, $N_2(\lambda;\eta)$, $N_3(\lambda;\eta)$, . . ., $N_{10}(\lambda;\eta)$ into the equation (69) give the complete solution as

$$\Psi(x,y,z) = \frac{1}{2D_z} \sum_{m=1}^{10} M_m(y) \int_0^\infty N_m(\lambda;\eta) \cos\left(\frac{\pi z}{2D_z}\eta \right) d\eta. \tag{84}$$

To evaluate the integral

$$\int_0^\infty N_m(\lambda;\eta) \cos\left(\frac{\pi z}{2D_z}\eta \right) d\eta,$$

we have computed the functions $N_m(\lambda;\eta)$ for

$\eta = 0.0, 0.1, 0.2, \ldots, 1.0, 2.0, 3.0, \ldots, 10.0$

and the process has to be carried out numerically between $\eta = 0$ and $\eta = 10.0$. For larger values of η, we may use the approximate formula (83).

Let the values of a function $F(\eta)$ for $\eta = 0$, h and $2h$ be F_0, F_1, and F_2 respectively. Then the interpolation formula in this interval of η will be given by

$$F(\eta) = F_0 + \frac{-3F_0 + 4F_1 - F_2}{2}\left(\frac{\eta}{h}\right) + \frac{F_0 - 2F_1 + F_2}{2}\left(\frac{\eta}{h}\right)^2,$$

Then we have

$$\int_0^{2h} F(\eta)\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta = F_0\int_0^{2h}\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta + \frac{-3F_0+4F_1-F_2}{2h}\int_0^{2h}\eta\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta + \frac{F_0-2F_1+F_2}{2h^2}\int_0^{2h}\eta^2\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta$$

or

$$\int_0^{2h} F(\eta)\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta = (a_1-3b_1+c_1)F_0 + (4b_1-2c_1)F_1 + (b_1+c_1)F_2$$

where

$$a_1 = \int_0^{2h}\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta = \frac{1}{\left(\frac{\pi z}{2D_z}\right)}\sin\left(\frac{\pi z}{2D_z}2h\right)$$

$$b_1 = \frac{1}{2h}\int_0^{2h}\eta\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta = \frac{1}{\left(\frac{\pi z}{2D_z}\right)}\frac{\left(\frac{\pi z}{2D_z}2h\right)\sin\left(\frac{\pi z}{2D_z}2h\right)+\cos\left(\frac{\pi z}{2D_z}2h\right)-1}{\left(\frac{\pi z}{2D_z}2h\right)} \tag{85}$$

$$c_1 = \frac{1}{2h^2}\int_0^{2h}\eta^2\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta = \frac{1}{\left(\frac{\pi z}{2D_z}\right)}\frac{2\left(\frac{\pi z}{2D_z}2h\right)\cos\left(\frac{\pi z}{2D_z}2h\right)+\left\{\left(\frac{\pi z}{2D_z}2h\right)-2\right\}\sin\left(\frac{\pi z}{2D_z}2h\right)}{\left(\frac{\pi z}{2D_z}2h\right)^2} \tag{86}$$

For larger values of η, we may express $F(\eta)$ in the form

$$F(\eta) = F_0 + \frac{F_{+1}-F_{-1}}{2h}(\eta-\eta_0) + \frac{F_{+1}-2F_0+F_{-1}}{2h^2}(\eta-\eta_0)^2$$

where F_{-1} F_0 and F_{+1} are the values of $F(\eta)$ for $\eta_0 - h$, η_0 and $\eta_0 + h$ respectively. We have then

$$\int_{\eta_0-h}^{\eta_0+h} F(\eta)\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta = (-b_2+c_2)F_{-1} + (a_2-2c_2)F_0 + (b_2+c_2)F_{+1} \tag{87}$$

where

$$a_z = \left\{1 - \frac{1}{6}\left(\frac{\pi z}{2D_z}h\right)^2\right\}\cos\left(\frac{\pi z}{2D_z}\eta_0\right)2h,$$

$$b_z = \left\{\frac{1}{3}\left(\frac{\pi z}{2D_z}h\right) - \frac{1}{30}\left(\frac{\pi z}{2D_z}h\right)^3\right\}\sin\left(\frac{\pi z}{2D_z}\eta_0\right)h,$$

$$c_z = \left\{\frac{1}{3} - \frac{1}{10}\left(\frac{\pi z}{2D_z}h\right)^2\right\}\cos\left(\frac{\pi z}{2D_z}\eta_0\right)h. \tag{88}$$

The integration was carried out taking $h = 0.1$ in the interval $0 \leqq \eta \leqq 1.0$; and $h = 1$ for the interval $1.0 \leqq \eta \leqq 10.0$. For larger values of η, integration was carried out by using the formula (82) which is only inversely proportional to η^2. In this case, we have only to evaluate the integral:

$$\int_{10.0}^{\infty}\frac{1}{\eta^2}\cos\left(\frac{\pi z}{2D_z}\eta\right)d\eta \tag{89}$$

The computations were rather tedious and took three computers more than six months to complete the surface, $1/2D_z$, D_z, $3/2D_z$, $2D_z$ and $3D_z$. The values of α, β, γ and δ which are the roots of the quadratic equations (73) with η as a parameter and computed for the necessary values of η, are compiled in Tables V to XIV (omitted).

The values of the stream-function were computed for the western-most 1/5 part of the entire expanse of the ocean, and the streamlines were drawn for the layers $z = 0$ (surface), $1/2D_z$, D_z, $3/2D_z$, $2D_z$, and $3D_z$. The computations were not carried out for the deeper levels and for the part to the east of this area, partly because we did not have enough time to compute, and partly because the central and eastern parts are not as interesting. We have only a very slow zonal flow in the central part and very diffuse meridional flow close to the eastern coast of the ocean. Indeed, the California and Peru Currents are considered to be produced by local winds as proved by Munk (1950).

The circulation patterns in the area close to the western coast were obtained from these computations, and illustrated in the Figures 3, 4, 5, and 6. The discussions for them will be given in the following paragraphs.

Table II gives the velocities of the western current in the subtropic gyre corresponding to the Kuroshio, or the Japan Current, at the depths $z = 0$ (surface), $1/2D_z$, D_z, $3/2D_z$, $2D_z$ and $3D_z$ along the 33° N parallel, which is the swiftest part of this mighty current. These velocities were computed by the formula:

$$v = \left(\frac{\partial \Psi}{\partial x}\right)_{\lambda_0} = \frac{\Psi(\lambda_0 + \Delta\lambda) - \Psi(\lambda_0 - \Delta\lambda)}{\text{linear distance of } 2\Delta\lambda},$$

TABLE II

COMPUTED VELOCITY * OF THE KUROSHIO AT DIFFERENT DEPTHS
$z = 0, 1/2D_z, 3/2D_z, 2D_z$ AND $3D_z$ ALONG THE 33° N PARALLEL,
ASSUMING $D_z = 75$ m

Distance from West Boundary (km)	0	25	50	75	100	125	150	175	200	225	250	275
Surface Velocity (cm/sec)	0	163	217	196	146	94	52	25	12	7	8	11
Velocity at $z = 1/2D_z$ (cm/sec)	0	150	206	186	135	84	43	17	4	0	1	4
Velocity at $z = D_z$ (cm/sec)	0	138	188	167	120	72	32	7	−5	−8	−6	−3
Velocity at $z = 3/2D_z$ (cm/sec)		123	168	149	104	47	21	9	−12	−14	−12	−8
Velocity at $z = 2D_z$ (cm/sec)	0	107	147	129	87	44	11	−9	−22	−19	−15	−11
Velocity at $z = 3D_z$ (cm/sec)	0	79	110	94	59	24	−3	−25	−25	−17	−18	−13

* To get the velocity for values of D_z other than 75 m, multiply these velocities by $75/D_z$, where D_z is expressed in meters.

and taking $D_z = 75$ meters. Because the velocity is inversely proportional to the quantity D_z, we can compute it for any other value of D_z. For this we have only to multiply these figures by $75/D_z$, where D_z is expressed in meters. The maximum surface velocity of 217 cm/sec agrees with actual observations very closely.

Table III gives the distribution of EW-components along a meridian 24° of longitude east of the western boundary, or 1/5 of the entire east-west expanse of the Pacific Ocean off the western coast. At this distance from the western coast the coastal effect nearly vanishes and the pattern of the circulation consists of approximately zonal flows. In this table the value of D_z was again assumed to be 75 meters. Discussions concerning these results will be made in the following paragraphs.

11. Surface Circulation

The numerical result for the horizontal circulation has been worked out for several levels specified by the ratio z/D_z. We show here those of the surface ($z = 0$), $z/D_z = 0.5$, $z/D_z = 1$, $z/D_z = 1.5$, $z/D_z = 2$ and $z/D_z = 3$. The most important of them is, of course, the surface circulation, and Figure 3 shows its pattern. The gross features of the current distribution on the surface thus do not seem to differ much from those given by Munk (1950) and by the author (1951) for the distribution of mass transport streamlines. Because of the considerable labor contained in the calculation, the computation is confined only to the western part of the ocean bounded by two meridians $\lambda = 0$ and $\lambda = 0.2$, that is, 24° of longitude apart. Choice of the western part of the ocean for the computation was made because the circulation patterns in that section are more complicated and hence more interesting. In the central part of the ocean we will have indeed a very slow motion approximately in east-west direction, while very diffuse meridional motion will exist close to the eastern coast.

We have a number of gyres in the surface circulation corresponding to those obtained in Munk's (1950) and the author's (1951) results with respect to mass transport. We have a broad gyre with strong western current flowing north in the latitudes between 20° and 40° N and corresponding to the Kuroshio or Japan Current. We also notice one boundary vortex, but the secondary boundary vortex is not distinct. We have a subtropic gyre with the western current flowing south. This corresponds to the Mindanao Current. Of course, we have a faint subarctic gyre corresponding to the Oyashio or the Kurile Current.

On the surface of the Southern Pacific Ocean, we have western currents flowing north a little south of the equator and in the subantarctic latitudes. Between these two we have a strong current cor-

TABLE III

ZONAL DISTRIBUTION OF EW-COMPONENTS OF OCEAN CURRENTS EXPRESSED IN cm/sec, ASSUMING $D_z = 75$ m (+ EASTWARD, − WESTWARD)

LAT.	$z = 0$ (SURFACE)	$z = 1/2D_z$	$z = D_z$	$z = 3/2D_z$	$z = 2D_z$	$z = 3D_z$	REMARKS
60° N	0	0	0	0	0	0	
57° N	0	− 1.2	2.1	2.7	2.9	− 2.8	Arctic
54° N	+ 2.5	+ 0.2	− 1.7	2.8	3.5	− 3.6	Current
51° N	+ 8.2	+ 5.0	+ 2.3	+ 0.5	− 0.7	− 1.7	
48° N	+ 15.3	+ 11.6	+ 8.6	+ 6.1	+ 4.2	+ 2.3	
45° N	+ 20.4	+ 16.7	+ 13.3	+ 10.7	+ 8.7	+ 5.9	West
42° N	+ 20.6	+ 17.4	+ 14.5	+ 12.2	+ 10.3	+ 7.3	Wind
39° N	+ 14.9	+ 12.8	+ 10.8	+ 9.2	+ 7.8	+ 5.7	Drift
36° N	+ 5.0	+ 4.3	+ 3.6	+ 3.0	+ 2.6	+ 2.0	
33° N	− 5.8	− 5.0	4.4	3.8	3.3	2.3	
30° N	14.1	12.1	10.3	8.8	7.4	5.3	
27° N	− 18.3	− 15.4	12.8	10.7	8.8	6.0	North
24° N	18.4	15.1	12.2	9.8	7.9	5.1	Equatorial
21° N	− 15.8	− 12.5	9.2	7.5	5.8	3.5	Current
18° N	11.8	8.9	− 6.5	4.6	3.3	− 1.7	
15° N	− 7.3	− 5.0	3.2	1.9	1.1	0.4	
12° N	− 2.7	− 1.2	0	+ 0.7	+ 1.0	+ 0.8	
9° N	+ 2.4	+ 3.3	+ 3.9	+ 4.0	+ 3.8	+ 2.8	Equatorial
6° N	+ 7.5	+ 7.0	+ 6.3	+ 7.1	+ 6.5	+ 4.8	Counter
3° N	+ 7.6	+ 8.2	+ 8.4	+ 8.2	+ 7.5	+ 5.7	Current
0°	+ 5.3	+ 6.3	+ 7.	+ 7.9	+ 6.7	+ 5.2	
3° S	− 0.7	+ 1.6	+ 3.7	+ 5.2	+ 5.2	+ 5.1	
6° S	− 6.9	− 6.4	− 4.1	2.5	− 1.5	− 0.5	
9° S	− 16.4	− 12.9	9.8	7.5	5.8	3.5	
12° S	− 22.9	− 16.8	12.3	8.9	6.2	− 5.2	South
15° S	24.5	17.6	14.1	11.4	9.1	5.9	Equatorial
18° S	18.2	14.9	12.9	9.5	7.5	4.8	Current
21° S	− 12.6	− 10.2	8.0	6.3	5.0	3.0	
24° S	5.9	4.8	− 3.7	3.0	2.3	− 1.4	
27° S	+ 1.2	+ 0.8	+ 0.6	0.4	0.3	0	
30° S	+ 8.2	+ 6.5	+ 5.0	+ 3.9	+ 3.0	+ 1.7	
33° S	+ 14.9	+ 12.0	+ 9.5	7.5	5.9	+ 3.5	West
36° S	+ 20.0	+ 16.5	+ 13.2	10.6	8.4	5.3	Wind
39° S	+ 22.4	+ 18.4	+ 14.8	+ 12.0	+ 9.7	+ 6.3	Drift
42° S	+ 20.0	+ 16.4	+ 13.1	12.5	+ 8.4	+ 5.6	
45° S	+ 13.7	+ 10.6	+ 7.9	6.0	4.7	3.0	
48° S	+ 5.0	+ 2.8	+ 1.0	0	0.5	0.6	
51° S	− 2.6	− 3.4	− 4.8	5.1	4.9	− 3.8	
54° S	6.2	6.8	7.2	8.0	6.4	4.8	Antarctic
57° S	− 4.8	− 5.0	5.1	4.9	4.4	3.3	Current
60° S	0	0	0	6	6	0	

responding to the East Australian Current, though actually this current never develops so strongly because of many passages connecting the Southern Pacific to the Indian Ocean through the numerous islands and archipelagoes in the Australian-Asiatic Mediterranean. Had we not these passages together with the Southern Antarctic Circumpolar Ocean, we could have a much stronger western current in the South Pacific Ocean than actually observed.

It looks also rather strange that we do not have any strong westward flow in the latitudes between 5° N and 2° S. Actually the northern margin of the South Equatorial Current is in this zone. This comes as the consequence that the Equatorial Counter Current appears in our theoretical result much broader and much more diffuse than actually observed. This is also the same in Munk's and Hidaka's results. The theory of the Equatorial Counter Current has been attacked and explained by several authors (Montgomery and Palmén, 1940, Neumann, 1947) in some other ways than ours.

12. Evaluation of the Coefficient of Vertical Mixing

The streamlines in Figure 3 are drawn for an interval

$$\Delta\Psi = 250 \times 10^{10}/D_z \text{ cm}^2/\text{sec.}$$

of the stream function. The velocity can be determined as the ratio $\Delta\Psi/\Delta x$, where Δx is the actual distance between two consecutive streamlines. Because these diagrams are not drawn in a common scale for the north-south and east-west directions, it would be rather laborous to compute the magnitude of current velocity for all parts of the Pacific. Still it will be easy to know it when the streamlines run in exactly north-south or east-west directions.

The values of the stream function at several points along the 33° N parallel are computed as compiled in Table IV. Assuming the Pacific Ocean is 10,000 kilometers across in its east-west direction, we obtained the velocity of the Kuroshio at its swiftest zone, which is located approximately 55 km off the coast, to be 329 cm/sec, 219 cm/sec, 165 cm/sec, and 110 cm/sec according as we assume D_z = 50 m, 75 m, 100 m and 150 m, respectively.

Actual velocity of the Kuroshio has been estimated at approximately 3 to 5 knots, or about 150 to 250 cm/sec in its swiftest zone. From Table IV we recognize that the computed velocity of the Kuroshio, assuming for D_z a value between 50 m and 150 m, agrees with the observed values fairly well. The previously determined values for D_z fall mostly in this range also. This enables us to compute the values of vertical coefficient of mixing from the formula (18). The above values of D_z correspond to the values 188, 422, 750 and 1688 g/cm/sec of A_z

TABLE IV

COMPUTATION OF THEORETICAL SURFACE VELOCITY OF THE KUROSHIO ACROSS THE 33° N PARALLEL

	$\lambda = 0$	.0025	.0050	.0075	.0100	.0125	.0150	.0175	.0200	.0225	.0250	.0275
Distance from West. boundary =	0	25	50	75	100	125	150	175	200	225	250	275 km
	$\psi = 0$	612	815	735	546	352	195	95	44	28	31	$41 \times \frac{10^{10}\text{cm}^2/\text{s}}{D_z}$
	$\Delta\psi/\Delta x = 0$	122.4	163.0	157.0	109.2	70.4	39.0	19.0	8.8	5.6	6.2	$8.2 \times \frac{10^{4}\text{cm}/\text{s}}{D_z}$
Computed Velocity	For $D_z = 50$ m: 0	245	326	314	218	141	78	38	18	11	12	16 cm/s
	For $D_z = 75$ m: 0	163	217	207	146	94	52	25	12	7	8	11 cm/s
	For $D_z = 100$ m: 0	122	163	157	109	70	39	19	9	6	6	8 cm/s
	For $D_z = 150$ m: 0	82	109	105	73	37	26	13	6	4	4	5 cm/s

respectively. These are, of course, values consistent with the results derived from many other different sources. (Sverdrup, *et al.*, 1942)

13. Subsurface Circulation

Figures 4, 5, 6, 7, and 8 show the horizontal distribution of streamlines in the level $\frac{1}{2}D_z$, D_z, $1\frac{1}{2}D_z$, $2D_z$, and $3D_z$ below the sea surface, respectively. All give patterns similar to the surface circulation shown in Figure 3. We have western currents and a boundary vortex attached to each gyre. The only difference noticed is a general subsidence of the motion as we go down into deeper layers. Still, we see that the intensity of motion is only reduced to as low as half that of the sea surface even in the layer $3D_z$. Figure 9 shows the comparison of the current velocity profiles along the 33° N parallel at several levels to that on the surface of the sea assuming $D_z = 75$ m. The maximum speeds are seen at about 55 kilometers off the western boundary. Although the Japanese Islands are not disposed parallel to a meridian, the above result agrees with the observed profiles of this mighty current quite satisfactorily. Another result of particular interest is that, at a distance larger than about 150 km, there is a flow to the south with much larger velocity than in upper layers. This counter current reaches a maximum speed of 20 to 30 cm/s at about 200 km off the western coast, despite the practically motionless upper layers. Figure 10 gives the comparison of the zonal distribution of EW-components along a meridian 24 degrees of longitude to the east off the western boundary. In this longitude it is expected that the influence of the western boundary nearly vanishes and the actual flow pattern of the Pacific circulation is disposed mostly as a zonal current system. The velocities of the current in these diagrams were computed assuming $D_z = 75$ meters. For computing the velocities when the value of D_z is different, we have only to multiply these figures by $75/D_z$, where D_z is expressed in meters. If we assume, however, that the value $D_z = 75$ m is consistent, we have for the maximum surface velocities of North Pacific Current, North Equatorial Current, Equatorial Counter Current, South Equatorial Current, and Antarctic Circumpolar Current 22, 19, 8, 23 and 23 cm/sec respectively. They are reduced to 18, 16, 8, 18 and 18 cm/sec respectively at a level $\frac{1}{2}D_z$ and to 11, 9, 8, 9 and 10 respectively at $2D_z$. The Equatorial Counter Current remains nearly unaltered in its speed in all depths compared above.

14. Vertical Variation of the Currents

The most important objective of the present research is to get a certain idea about the vertical structure of the wind-driven circulation in the Pacific Ocean. This will be, of course, impossible to obtain from

former theories which have been mostly propounded with respect to the mass transport.

Since the problem is three-dimensional, the numerical computation is rather tedious. For this reason the author has not yet been able to finish the computation below the level $z = 3D_z$. Still we should be able to expect some important conclusions from what has been completed thus far.

First of all it is very interesting that the wind-driven currents exist in a layer much deeper than that expected from the classical theory of Ekman (1905). According to Ekman's theory, a wind driven current is confined to the surface layer about D_z thick, and we can expect practically no drift current at a deeper level except very close to the equator. From our computation, it can be shown that the current velocity does not drop as low as half the surface value even at a level $3D_z$. If we take $D_z = 75$ meters, this depth is 225 meters.

This conclusion will be helpful for us to understand the fact that wind-driven currents can penetrate into a layer several hundred meters deep, a layer several times as deep as that expected from Ekman's theory as the limit of the wind-driven currents. This implies that the motion of water in most parts of the *oceanic troposphere* could be produced by the stresses of the permanent wind system prevailing over the oceans. In other words, the winds are responsible not only for the currents in the skin layer of the ocean, but also for the most part of the circulation in the oceanic troposphere.

We have long considered that the winds are responsible only for the current motion in the surface layer of about 100 meters thick. This depth is nothing but the "depth of the frictional influence" defined by Ekman. To explain the circulation in deeper parts of the troposphere, we had to assume a very strong convection current and slope current. Still we had a distinct difference in the circulation patterns between the troposphere and stratosphere. These circumstances have made several problems very much complicated. Defant (1928) defined the troposphere as the part of the ocean in which we can expect strong currents due to violent turbulence and convection. Still we can have violent convection in the seas of higher latitudes beyond the polar fronts which are no longer defined as troposphere. The conclusion that the drift currents penetrate into much deeper layers than D_z is much in favor of the definition of troposphere that this is the upper layer of the ocean in which strong currents are present.

The explanation of the result that we can have a strong motion even in a layer several hundred meters deep might look possible by assuming slope currents which would be produced as the effect of purely

wind-driven water masses piled up against the land barriers. As a matter of fact, Ekman's theory assumes no boundaries and a constant latitude. We can prove the existence of slope current in an ocean having boundaries partly or completely enclosing it. The slope current is uniform from the surface down to the bottom. This fact seems in favor of the theoretical result we have obtained. Still, we must give attention to the fact that the velocity of slope current is always inversely proportional to the depth of the sea. When the depth is large as we see in the actual oceans, the slope current will not be strong enough to account for those large velocities we have obtained at the depth twice or three times as large as D_z.

We don't know an appropriate explanation of the theoretical result that the effect of winds can be felt at a depth several times as large as Ekman's depth of frictional influence. It would be hoped someone may be able to solve this question satisfactorily in the near future.

15. Summary

(1) A theory of the general circulation of water in the Pacific Ocean produced by the semi-permanent wind system prevailing over this ocean is propounded.

(2) The velocity is used to express the water motion which has formerly been explained by several authors in terms of mass transport.

(3) The Pacific Ocean is considered to be a rectangular ocean extending from 60° S to 60° N latitudes and from 0° to 120° longitude, and a zonal distribution of the wind system determined from actual observations has been assumed.

(4) The effects of horizontal turbulence and the meridional variation of the Coriolis forces have been taken into account.

(5) The patterns of horizontal circulation are obtained in terms of streamlines for the sea surface and several deeper layers specified by the ratio z/D_z where z is the geometrical depth below the surface and D_z the depth of the frictional influence, a measure of vertical turbulence.

(6) Surface circulation has a pattern similar to that actually observed and does not differ much from Munk's result obtained in terms of mass transport. We have very strong western currents and boundary vortices.

(7) The magnitude of the Kuroshio and other western currents was computed from the distribution of the streamlines in each level. The velocity is inversely proportional to D_z so that we can determine it by assuming an appropriate value for D_z. A value of D_z between 50 m and 150 m gives values most reasonable and consistent with the actual observations.

(8) Subsurface circulations also show similar patterns except for a general subsidence as we go down into deeper layers. Still, it is remarkable that we have far stronger currents than expected from Ekman's classical theory even at a depth much larger than Ekman's depth of frictional influence at which we can scarcely expect any motion except very close to the Equator. This seems to show us that the winds are responsible for the most part of the tropospheric motion of water.

16. Acknowledgments

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It is the author's utmost pleasure here to express his deepest thanks to all who helped him in carrying out this research.

June 17, 1953

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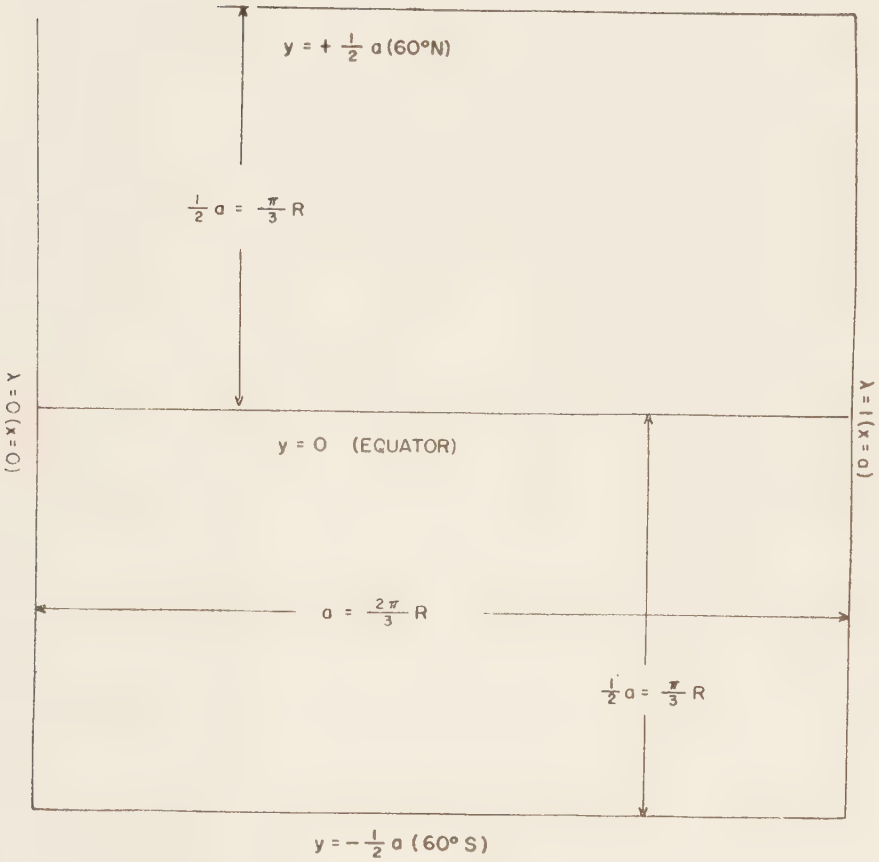

FIG. 1.—A Rectangular Ocean comparable in size to the Pacific Ocean.

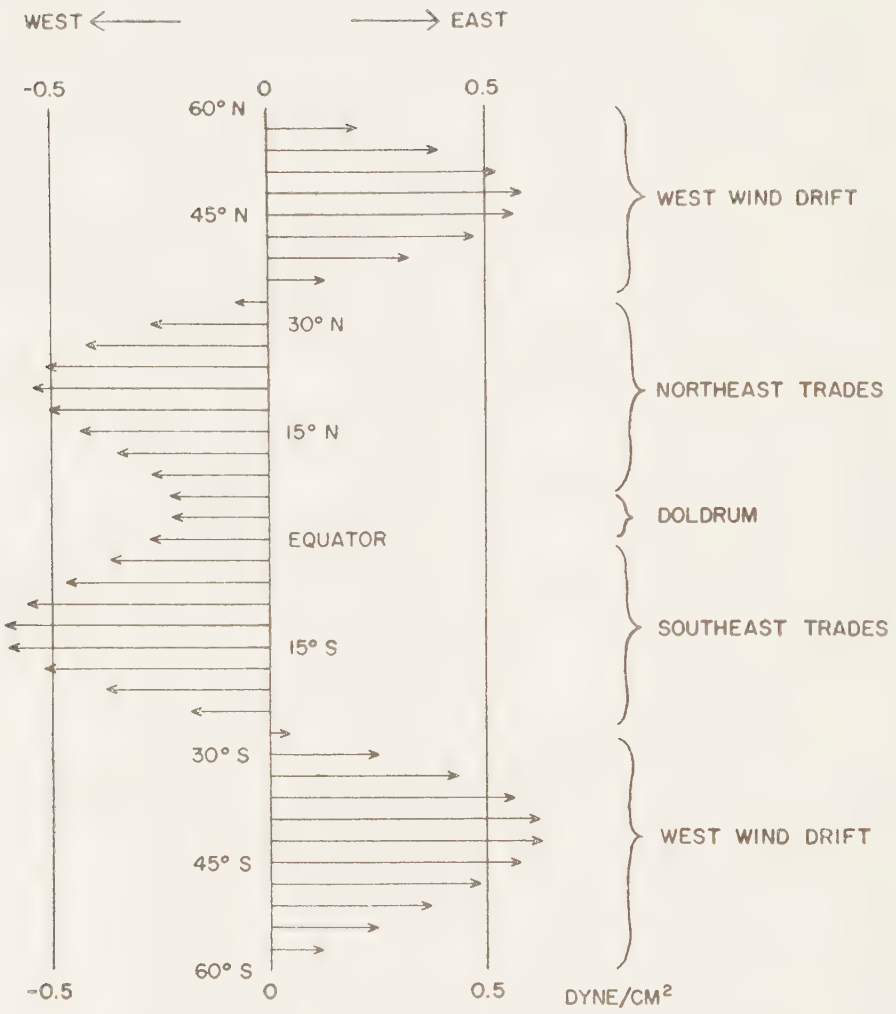

FIG. 2.—Assumed meridional distribution of wind stress.

Fig 3
COMPUTED SURFACE CIRCULATION OF THE WESTERN PART OF THE PACIFIC OCEAN

Fig 4
COMPUTED CIRCULATION IN A LEVEL $Z+\frac{1}{2}D_z$ IN THE WESTERN PART OF THE PACIFIC OCEAN

Fig 5
COMPUTED CIRCULATION IN A LEVEL $Z+D_z$ IN THE WESTERN PART OF THE PACIFIC OCEAN

Fig. 6
COMPUTED CIRCULATION IN A LEVEL $Z=1\cdot5D_2$ IN THE WESTERN PART OF THE PACIFIC OCEAN

Fig. 7
COMPUTED CIRCULATION IN THE LEVEL $Z=2\cdot0D_2$ IN THE WESTERN PART OF THE PACIFIC OCEAN

Fig. 8
COMPUTED CIRCULATION IN A LEVEL $Z=3\cdot0D_2$ IN THE WESTERN PART OF THE PACIFIC OCEAN

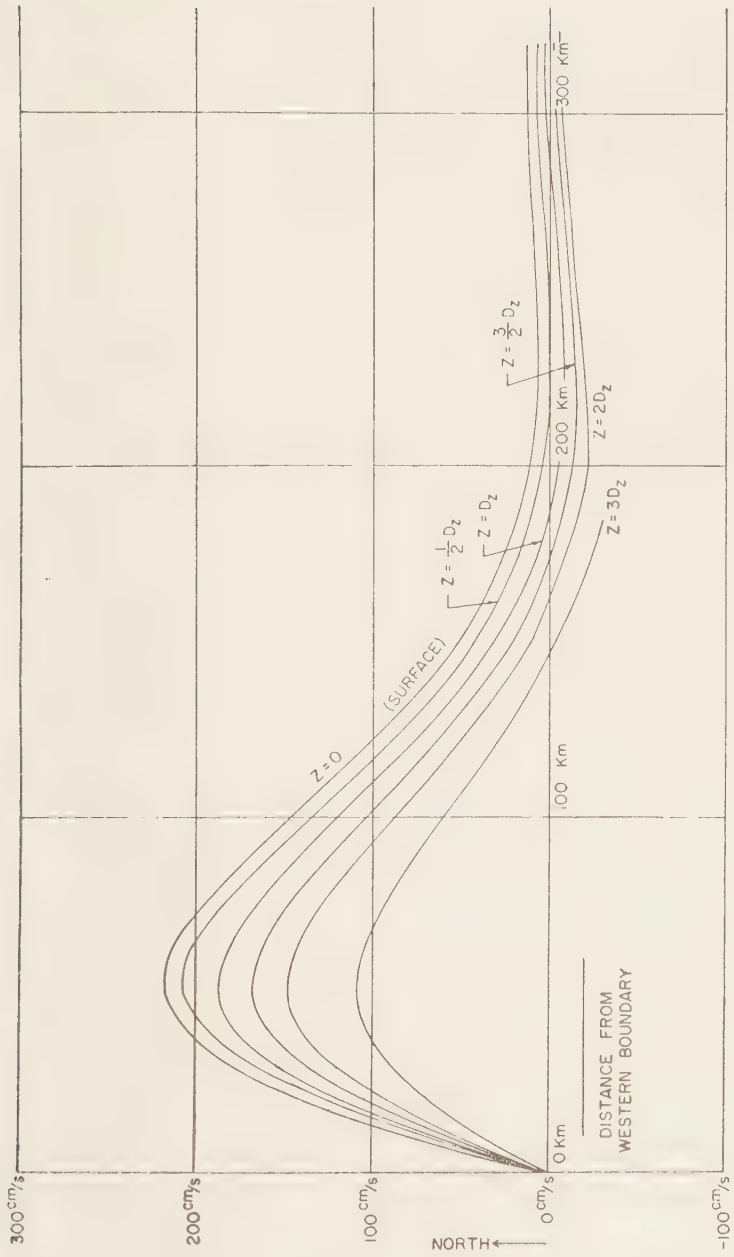

FIG. 9.—Theoretical velocity profiles of the Kuroshio at several different depths below the surface, along the 33° N Parallel, assuming $D_z = 75$ m. (To get the profiles for D_z other than 75 m, multiply these velocities by $75/D_z$ where D_z is expressed in meters.)

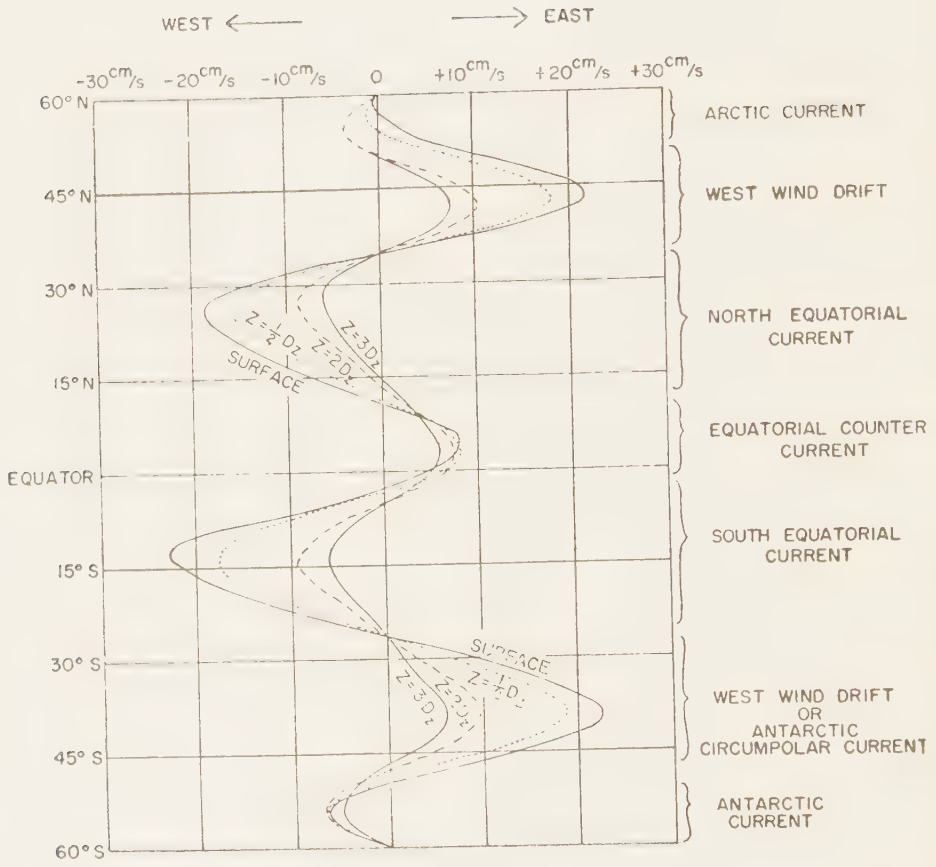

FIG. 10.—Zonal distribution of 1W-components of ocean currents at several depths expressed in cm/s, when $D_z = 75$ meters. (To get the velocity for other values of D_z multiply these velocities by $75/D_z$ where D_z is expressed in meters.)

A CONTRIBUTION TO THE THEORY OF UPWELLING AND COASTAL CURRENTS *

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1. Introduction

There have been several descriptions of the upwelling noticed off California, Peru, West Africa and other coasts by Thorade (1909), McEwen (1912, 1929), Gunther (1936), Defant (1936, 1952), Sverdrup (1931, 1938) and Sverdrup and Fleming (1941). The explanation of this process given by Sverdrup in 1938 is worth attention. According to Sverdrup and Fleming, it is known from the analysis of the water masses that the water taking part in the process of upwelling off the coast of Southern California originates mostly in the layers from 200 to 300 meters below the surface. These are, however, all qualitative discussions and it has been as yet not possible to explain this phenomenon theoretically and predict the velocity and width of the coastal currents produced by the prevailing winds. Very recently Defant (1952) made a theoretical explanation assuming a sea consisting of two layers of water with different densities. The present research is an attempt to solve this problem mathematically and to draw some quantitative conclusions concerning this process, which is very important in all fields of oceanography.

The explanation of the upwelling seems to be satisfactory only by treating this problem thermodynamically as well as hydrodynamically. The following discussion will, however, be made only from a purely hydrodynamical standpoint, on the assumption that the seawater is of uniform density. This is a necessary consequence for simplifying the mathematics, but the author believes to have been able to obtain some results which are consistent with certain facts observed in this process.

It has been noticed that the upwelling takes place most favorably when, in the northern (southern) hemisphere, a wind blows in such a manner that the coast is on the left-hand (right-hand) side of an observer who looks in the direction of the wind. Thus the upwelling off the coast of California is most remarkable in early summer when northwesterly winds prevail for several weeks nearly parallel to the coast.

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consideration. And it may be stressed that the horizontal mixing seems to play the most important role in the theoretical explanation of the process of upwelling.

2. Theory

Consider an infinitely long straight coast coincident with the axis of y, and take x-axis perpendicular to it in the offshore direction. (Fig. 1). Suppose a wind of constant force and direction is blowing steadily and uniformly in a belt of limited width L parallel to the coast from negative to positive direction of y. This is a disposition favorable for the upwelling to actually occur. Take the z-axis vertically downwards.

In a steady state which is attained after a sufficiently long time since the wind began to blow constantly, the motion of water will be independent of y. This means that all the vertical and horizontal components of the currents can be determined as functions of x and z only. Moreover, the surface of the sea will not be a plane, but have a slope in the x-direction. In such a case, the hydrodynamical equations of motion of sea water are, after several reasonable simplifications,

$$\begin{aligned} \frac{A_h}{\rho}\frac{\partial^2 u}{\partial x^2} + \frac{A_v}{\rho}\frac{\partial^2 u}{\partial z^2} + 2\omega \sin\phi v - g\frac{\partial \zeta}{\partial x} &= 0 \\ \frac{A_h}{\rho}\frac{\partial^2 v}{\partial x^2} + \frac{A_v}{\rho}\frac{\partial^2 v}{\partial z^2} - 2\omega \sin\phi u &= 0 \end{aligned} \tag{1}$$

where u and v are the horizontal components of the current velocity in the x and y directions, ζ the surface elevation depending on x only, ρ the density, A_v and A_h the coefficients of vertical and horizontal mixing, of sea water, ω the angular velocity of the Earth and ϕ the geographic latitude. In addition to these, we have the equation of continuity in the form:

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 \tag{2}$$

where w is the vertical component of currents and represents the intensity of the upwelling, and because $\partial v/\partial y = 0$.

Suppose the wind blows in the positive direction of y in a belt between the coast $x = 0$ and $x = L$. The wind velocity may vary in the offshore or x-direction. The conditions to be satisfied on the surface of the sea are therefore at

$$z = 0: \quad \begin{cases} -A_v\dfrac{\partial u}{\partial z} = 0 \\ -A_v\dfrac{\partial v}{\partial z} = \tau \quad \text{for } 0 \leqq x \leqq L \\ \qquad\qquad = 0 \quad \text{for } L < x < \infty \end{cases} \tag{3}$$

where τ is the stress of wind and may be either a constant or a function of x. On the bottom we must have no motion, because of the vertical friction at $z = h$:

$$u = v = 0, \tag{4}$$

and along the coast, which is considered to consist of vertical cliffs, we have because of the horizontal friction at $x = 0$:

$$u = v = 0. \tag{5}$$

In the region very far from both the coast and wind region, we have at $x = \infty$:

$$u = v = -\frac{\partial \zeta}{\partial x} = 0. \tag{6}$$

Let us define D_v and D_h by

$$D_v = \pi\sqrt{A_v/\rho\omega \sin \phi}; \qquad D_h = \pi\sqrt{A_h/\rho\omega \sin \phi}. \tag{7}$$

D_v is the depth of frictional influence defined by Ekman (1905) in his theory of ocean currents, and D_h is a quantity having a dimension of a length and may be called "frictional distance." This is a measure of the horizontal turbulence. Then the equations (1) now become

$$\left.\begin{aligned} &\frac{\partial^2 u}{\partial \xi^2} + D_v^2 \frac{\partial^2 u}{\partial z^2} + 2\pi^2 v - \frac{\pi^2 g}{\omega \sin \phi} \frac{\partial \zeta}{\partial \xi} = 0, \\ &\frac{\partial^2 v}{\partial \xi^2} + D_v^2 \frac{\partial^2 v}{\partial z^2} + 2\pi^2 u = 0 \end{aligned}\right\} \tag{8}$$

where

$$\xi = \frac{x}{D_h}. \tag{9}$$

In order to solve the equations (8), suppose

$$\left.\begin{aligned} u = \frac{2}{\pi}\int_0^\infty u_1(\lambda) \sin \lambda\xi d\lambda, \\ u_1(\lambda) = \int_0^\infty u(\alpha, z) \sin \lambda\alpha d\alpha \end{aligned}\right\} \tag{10}$$

$$\left.\begin{aligned} v = \frac{2}{\pi}\int_0^\infty v_1(\lambda) \sin \lambda\xi d\lambda, \\ v_1(\lambda) = \int_0^\infty v(\alpha, z) \sin \lambda\alpha d\alpha \end{aligned}\right\} \tag{11}$$

$$\left.\begin{aligned} \frac{\partial \zeta}{\partial \xi} &= -\frac{2}{\pi}\int_0^\infty \gamma(\lambda)\,\sin\,\lambda\xi d\lambda, \\ \gamma(\lambda) &= \int_0^\infty \frac{\partial \xi}{\partial \alpha}\sin\,\lambda\alpha d\alpha. \end{aligned}\right\} \tag{12}$$

Next assume for the wind stress

$$-A_v\frac{\partial v}{\partial z} = -\frac{2}{\pi}\int_0^\infty T(\lambda)\,\sin\,\lambda\xi d\lambda \tag{13}$$

and

$$T(\lambda) = \int_0^\infty \left(-A_v\frac{\partial v}{\partial \alpha}\right)\sin\,\lambda\alpha d\alpha$$

$$= \int_0^{L/D_h} \tau\,\sin\,\lambda\alpha d\alpha$$

$$= \frac{1-\cos(\lambda L/D_h)}{\lambda}\tau \tag{14}$$

if τ is independent of x.

Substituting (10), (11) and (12) into (8) and writing

$$u_1 + iv_1 = \overline{W} \tag{15}$$

the two equations (8) are combined into

$$D_h^2\frac{d^2\overline{W}}{dz^2} - (\lambda^2 + 2\pi^2 i)\,\overline{W} - \frac{\pi^2 g}{\omega\sin\phi D_h}\gamma(\lambda) = 0 \tag{16}$$

and the conditions to be satisfied along the boundaries now become

$$z = 0: \quad -A_v\frac{d\overline{W}}{dz} = \frac{1-\cos(\lambda L/D_h)}{\lambda}i\tau \tag{17}$$

and

$$z = h: \ \overline{W} = 0. \tag{18}$$

The solution of the equation (16) subject to the conditions (17) and (18) is

$$\overline{W} = \frac{\pi^2 g\gamma(\lambda)}{(\lambda^2 + 2\pi^2 i)\omega\sin\phi D_h}\left\{1 - \frac{\cos h\,(\sqrt{\lambda^2 + 2\pi^2 i}\,z/D_v)}{\cos h\,(\sqrt{\lambda^2 + 2\pi^2 i}\,h/D_v)}\right\}$$

$$+ \frac{i\tau D_v/A_v}{\sqrt{\lambda^2 + 2\pi^2 i}}\,\frac{1-\cos(\lambda L/D_h)}{\lambda}\,\frac{\sin h\,(\sqrt{\lambda^2 + 2\pi^2 i}\,\frac{h-z}{D_v})}{\cos h\,(\sqrt{\lambda^2 + 2\pi^2 i}\,h/D_v)} \tag{19}$$

If we separate the real part P of $\sqrt{\lambda^2 + 2\pi^2 i}$ from the imaginary part Q, we have

$$P = \sqrt{(\sqrt{\lambda^4 + 4\pi^4} + \lambda^2)/2} \qquad Q = \sqrt{(\sqrt{\lambda^4 + 4\pi^4} - \lambda^2)/2} \tag{20}$$

Thus the real part of $\sqrt{\lambda^2 + 2\pi^2 i}$ is always greater than π. Hence, if the depth of the sea is sufficiently large ($h/D_v > 2$), the expression (19) can be given very accurately by

$$\overline{W} = \frac{\pi^2 g\gamma(\lambda)}{(\lambda^2 + 2\pi^2 i)\omega \sin\phi D_h}\left(1 - e^{-\sqrt{\lambda^2 + 2\pi^2 i}\ \frac{h-z}{D_v}}\right) + \frac{i\tau D_v}{A_v}\frac{1}{\sqrt{\lambda^2 + 2\pi^2 i}}\frac{1 - \cos(\lambda L/D_v)}{\lambda} e^{-\sqrt{\lambda^2 + 2\pi^2 i}\ z/D_v} \tag{21}$$

Now we have, for the vertical component w,

$$w = 0 \text{ at } z = 0; \quad z = h \tag{22}$$

since there can be no vertical motion on the surface and bottom of the sea. Integrating (2) with respect to z from the surface down to the bottom, we have

$$\frac{\partial}{\partial x}\int_0^h u\,dz = w\Big|_{z=0}^{z=h} = 0$$

This means that the integral $\int_0^h u\,dz$

is independent of x, or therefore a constant. But as this integral must vanish directly on the coast or at $x = 0$, we must have

$$\int_0^h u\,dz = 0 \tag{23}$$

always. Integrating (21) with respect to z from 0 to h and equating the real part of the resulting equation to zero, we have

$$\gamma(\lambda) = \frac{\pi^2\tau/\rho\omega}{\frac{\lambda^2}{2\pi^2}\left(h - \frac{P}{P^2 + Q^2}D_v\right) + \frac{Q}{P^2 + Q^2}D_v}\frac{1 - \cos(\lambda L/D_h)}{\lambda} \tag{24}$$

This determines the relation between the wind stress τ and slope of the sea surface induced by the former. Substitution of (24) in (21) gives u_1, and v_1. The substitutions of u_1, v_1 and $\gamma(\lambda)$ thus obtained into (10), (11) and (12) give u, v and the surface slope $\partial\zeta/\partial\xi$. The vertical velocity w can be derived from the equation of continuity (2) as

$$w = -\frac{\partial}{\partial x}\int_0^z u\,dz \tag{25}$$

3. Upwelling in a Deep Sea

When the sea is sufficiently deep and the ratio h/D_v increased indefinitely, we have from (24)

$$\gamma(\lambda) = 0 \tag{26}$$

and (21) becomes

$$\overline{W} = \frac{i\tau D_v/A_v}{\sqrt{\lambda^2 + 2\pi^2 i}} \frac{1 - \cos(\lambda L/D_h)}{\lambda} e^{-\sqrt{\lambda^2 + 2\pi^2 i}\, z/D_v} \tag{27}$$

Then we have

$$u(x,z) = \frac{2\pi\tau}{\rho\omega \sin\phi D_v}\int_0^\infty M(\lambda,z)\,R(\lambda,x)\,d\lambda \tag{28}$$

$$v(x,z) = \frac{2\pi\tau}{\rho\omega \sin\phi D_v}\int_0^\infty N(\lambda,z)\,R(\lambda,x)\,d\lambda \tag{29}$$

$$w(x,z) = \frac{2\pi\tau}{\rho\omega \sin\phi D_v}\left(\frac{D_v}{D_h}\right)\int_0^\infty L(\lambda,z)\,S(\lambda,x)\,d\lambda \tag{30}$$

where

$$M(\lambda,z) = \frac{Q\cos(Qz/D_v) + P\sin(Qz/D_v)}{P^2 + Q^2} e^{-Pz/D_v} \tag{31}$$

$$N(\lambda,z) = \frac{P\cos(Qz/D_v) - Q\sin(Qz/D_v)}{P^2 + Q^2} e^{-Pz/D_v} \tag{32}$$

$$L(\lambda,z) = \frac{2PQ\{\cos(Qz/D_v)e^{-Pz/D_v} - 1\} + (P^2 - Q^2)\sin(Qz/D_v)e^{-Pz/D_v}}{(P^2 + Q^2)^2} \tag{33}$$

$$R(\lambda,x) = \sin(\lambda x/D_h)\frac{1 - \cos(\lambda L/D_h)}{\lambda} \tag{34}$$

$$S(\lambda,x) = \cos(\lambda x/D_h)\{1 - \cos(\lambda L/D_h)\} \tag{35}$$

and P and Q are the real and imaginary part of $\sqrt{\lambda^2 + 2\pi^2 i}$ whose expressions are given by (20).

These results show that, by the effect of the wind blowing parallel to the coast, we can expect a vertical circulation in the plane perpen-

dicular to the coast in addition to a coastal current parallel to the direction of the wind. The vertical component of this circulation evidently represents the upwelling.

From the expressions (28), (29) and (30) for u, v and w, it can be expected that the horizontal velocity of the water in this process is approximately D_h/D_v or $\sqrt{A_h/A_v}$ times as large as the vertical velocity. This result will be very useful in estimating the approximate speed of upwelling. But this kind of vertical circulation can be noticed best in the case of a very deep sea where there is very little current produced by the slope of the surface of the sea.

If we define a function $\Psi(x, z)$ as

$$\Psi(x,z) = \frac{2\pi\tau}{\rho\omega \sin\phi} R \int_0^\infty \frac{\sin \lambda x/D_h \,(1 - \cos \lambda L/D_h)}{\lambda\sqrt{\lambda^2 + 2\pi^2 i}} \left\{ e^{-\sqrt{\lambda^2 + 2\pi^2 i}\, z/D_v} - 1 \right\} d\lambda \tag{36}$$

we can show that this is the stream function in the plane perpendicular to the coast and u and w are given by

$$u = -\frac{\partial \Psi}{\partial z} \quad ; \quad w = \frac{\partial \Psi}{\partial x} \tag{37}$$

so that any curve

$$\Psi(x, z) = \text{constant}$$

represents a stream line.

4. A Numerical Example

So far the author has elucidated the process of upwelling in a quantitative manner and obtained the expressions representing the motion of water produced by a wind blowing parallel to the coast in a belt of finite width. The stream-function $\Psi(x, z)$ can be computed from the formula (36) for any distance x/D_h and for any depth z/D_v below the sea surface where D_h and D_v are the distance and depth specifying the intensity of the horizontal and vertical mixing respectively. The result of computation of the stream function is given in the Table I and illustrated by the diagram in Figure 2. The unit is given by

$$\frac{2\pi\tau}{\rho\omega \sin\phi} \times 10^{-4}$$

From the table and diagram it can be easily shown that the vertical circulation is most strongly developed close to the coast and in the upper layers of the sea directly below the surface swept by the wind. An in-

tense upwelling can be seen in the belt within $0.5D_h$ from the coast-line and the stream-lines go down gradually outside the wind zone. This means that beyond the wind zone there occurs the process of sinking.

The fact that the expressions for the velocity components all include sin ϕ in the denominator shows that the lower the latitude the more intense will be the process of upwelling. Perhaps the strong upwelling off the Peruvian coast may be ascribed to this theoretical result.

It will be interesting and useful to compute the magnitude of the off-shore currents and the velocity of upwelling from the stream-function given by (36) and to compare them with the values formerly estimated from various sources.

It is of course not easy to estimate the magnitude of the coefficients of mixing. The vertical mixing coefficient may be estimated at something like 1000 c.g.s. If we adopt this value, D_v is about 162 meters for a latitude of 30° N. To estimate A_h is even more difficult. But actual oceanographic observations show that $A_h/A_v = 10^6$ approximately. This means that D_h is just about 1000 times as large as D_v, or 162 kilometers. Furthermore, we do not know much about the width of the coastal wind belt. In this computation, the author tentatively assumed $L = 2.0944 \times D_h$ that is, about twice as large as D_h; or at 339 kilometers.

It will be still more difficult to estimate the wind velocity of the northwesterlies prevailing off the coast of Southern California in the earlier summer months. The author took $\tau = 1$ c.g.s. This corresponds to a wind velocity between 5 and 6 m/s. If we consider the upwelling off the coast of southern California and take $\phi = 30°$ N, we have

$$\frac{2\pi\tau}{\rho\omega \sin \phi} = 2.37 \times 10^5 \text{ sec}^{-1}$$

From the table we can compute the average velocity between the surface and the layer $0.2D_v$ deep by

$$-\frac{2\pi\tau}{\rho\omega \sin \phi} \frac{\Delta\Psi}{\Delta z} = 2.37 \times 10^5 \times \frac{0.045}{0.2D_v} = 3.35 \text{ cm/sec (offshore)}$$

This is the maximum velocity of the offshore current in the layer between the surface and the 32.4 meters level.

The maximum vertical velocity can be estimated in a similar way, viz., at

$$\frac{2\pi\tau}{\rho\omega \sin\phi}\frac{\Delta\Psi}{\Delta x} = -2.37 \times 10^5 \times \frac{0.033}{0.14 D_h} = -3.14 \times 10^{-3} \text{ cm/sec (upward)}$$
$$= -2.7 \text{ m/day.}$$

This speed of upwelling is just about *80 meters per month.*

G. F. McEwen (1929) estimated the speed of upwelling off the coast of Southern California at about 10–20 meters per month. The present result appears to show a speed a little too high, but may be suggestive of the order of magnitude of ascending motion in the process of upwelling.

From the diagram in Figure 2, we can see that the water mass participating in this process comes up from the layers from $z = D_v$ to $1.5D_v$ or more. If we take $D_v = 162$ m, the layers from which the upwelled waters originate are located somewhere around the layers 200 meters or deeper. This also agrees with Sverdrup-Fleming's estimation derived from practical observations off the coast of Southern California.

5. Coastal Currents

In addition to the circulation in a vertical plane perpendicular to the coast, we have a current parallel to the coast. The author thinks that this will be another subject of major interest.

The model treated in this research is very simple, the winds being assumed always to blow parallel to the coast. But it may be considered that a certain pattern of water motion will always correspond to the wind of any direction. The investigation into this problem seems suggestive of the explanation of several facts observed close to the shore in relation to the motion of the water.

6. Acknowledgments

The author hereby expresses his sincerest appreciation to Dr. Dale F. Leipper, Head of the Department of Oceanography, Agricultural and Mechanical College of Texas, who encouraged the author in carrying out the present research and publishing the result during his stay in the department. He is also much obliged to Mr. Robert O. Reid and Dr. John T. Hurt who kindly discussed on the result.

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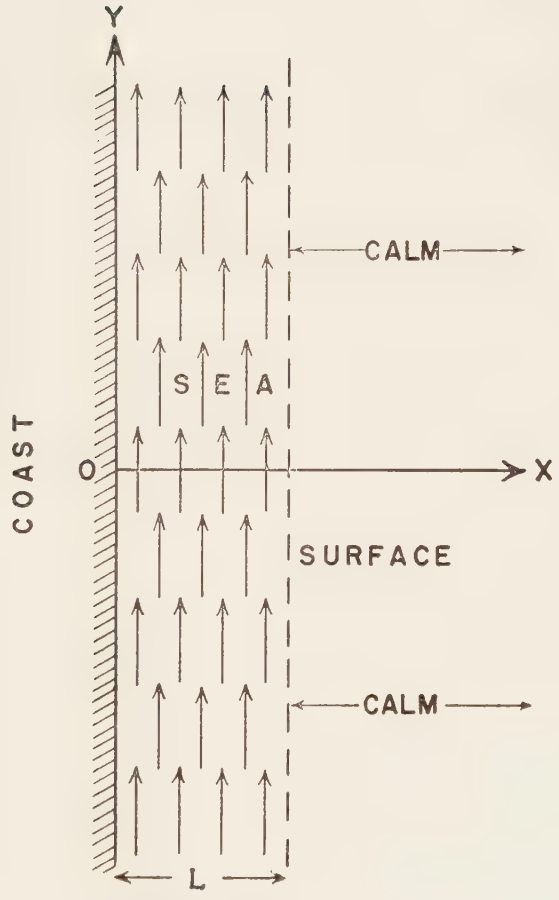
TABLE I

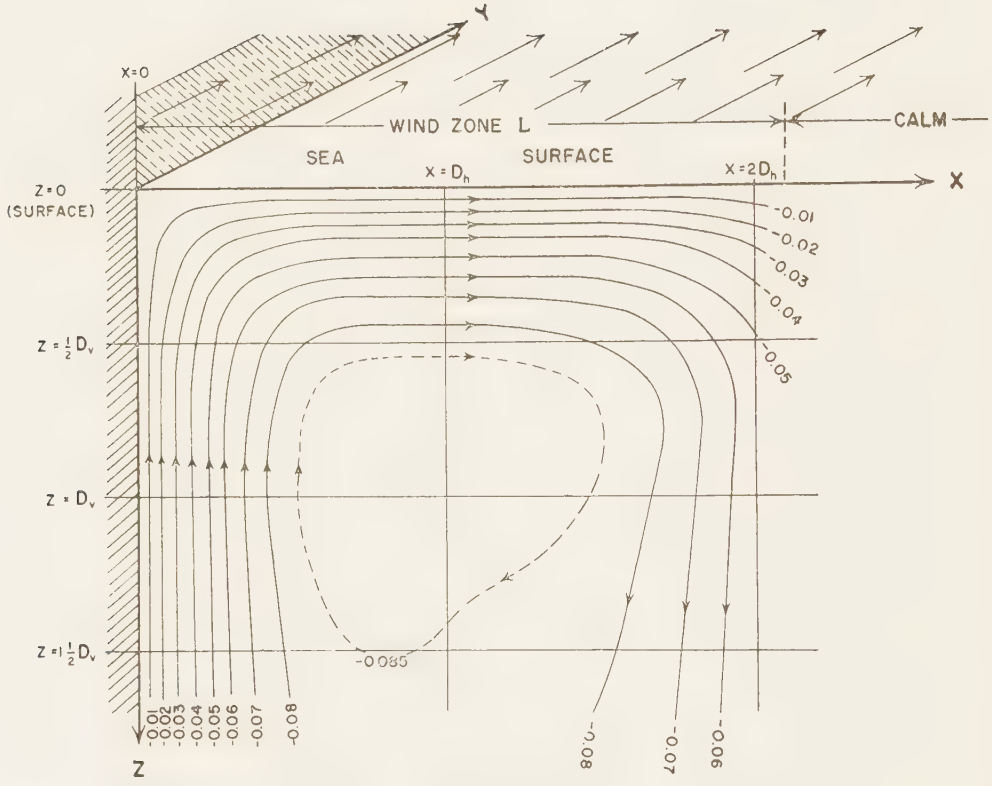
NUMERICAL VALUES OF THE STREAM FUNCTION IN THE VERTICAL PLANE PERPENDICULAR TO THE COAST

$$\left(\times \frac{2\pi\tau}{\omega\rho \sin \phi} 10^{-4}\right)$$

z/D_v \ x/D_h	0	0.1396	0.279	0.559	0.838	1.117	1.396	1.676	1.955
0	0	0	0	0	0	0	0	0	0
0.2	0	−175	−313	−449	−461	−465	−455	−425	−310
0.4	0	−277	−499	−725	−748	−750	−734	−682	−496
0.6	0	−321	−578	−843	−867	−866	−848	−788	−576
0.8	0	−334	−600	−871	−891	−887	−869	−808	−589
1.0	0	−332	−598	−865	−890	−873	−856	−797	−579
1.2	0	−329	−592	−852	−863	−853	−837	−782	−568
1.4	0	−327	−587	−844	−853	−843	−823	−773	−561
1.6	0	−326	−585	−840	−848	−837	−827	−769	−558



SCHEMATIC DIAGRAM OF WIND TO COAST RELATIONSHIP
OR THE DEVELOPMENT OF UPWELLING IN THE NORTHERN HEMISPHERE
FIGURE 1



UPWELLING AS INDUCED BY A WIND PARALLEL TO THE COAST
(ILLUSTRATED BY THE STREAMLINES IN THE VERTICAL PLANE PERPENDICULAR TO THE COAST)

FIGURE 2

SURFACE WATERS OFF THE CANADIAN PACIFIC COAST

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In 1950 the Pacific Oceanographic Group undertook an exploratory investigation of the physical oceanographic conditions in the Pacific Ocean within some 300 to 650 miles west of the Canadian coast (Figure 1). Four surveys were completed, in August 1950, May 1951, August 1951, and March 1952. These included serial observations of temperature and salinity to depths variously of 900, 1000, and 1200 metres on the several cruises. Although the four cruises were observed in different years it is convenient in some cases to regard the data in sequence of seasons.

Structure and Physical Properties of the Water

The most conspicuous characteristic of the water structure of this area is the presence of the distinct layers, or zones.* These are conveniently illustrated by plotting the properties as functions of the logarithm of depth as shown in Figure 2 (Tully, 1948, 1953). In this figure the surface zone is defined by the logarithmic salinity-depth relation extending to about 80 metres, the lower zone by the logarithmic relation below 180 metres, and the salicline is regarded as a transition zone between these two principal water masses. A similar but not concurrent structure occurs in the temperature.

In winter (March 1952) the properties of the upper zone approach vertical homogeneity due to cooling at the surface and vigorous mixing by winter storms. At this time the temperature and salinity structure correspond. As vernal heating progresses (May 1951) the surface waters are warmed and a shallow thermocline develops which gradually deepens and becomes more pronounced as summer progresses (August 1950, 1951). With the advent of autumn weather and storms in September, the surface waters are cooled and the winds cause mixing to greater and greater depths. In this process the thermocline sinks, becoming less distinct, until late winter (March) it coincides with the salicline.

During the summer the fresh water from precipitation and land drainage is conserved near the surface in the presence of light winds

* Tully, in his discussion of the oceanography of Alberni Inlet (1949) has used the term "zone" to designate the principal layers in the water structure. This term has the advantage of being more specific in its reference than "layer", which is used variously to designate horizontal strata of any order.

and strong thermal gradients. In the winter there is much greater precipitation but the fresh water is mixed to great depths by the violent winter winds, which also reduce the thermal gradient.

The seasonal variation occurs only in the surface zone, and never extends below the salicline. Thus the properties of the water at this boundary are associated with the extreme of winter conditions. Due to the strong salinity gradient, it is the zone of permanent stability maximum below the depth of seasonal influence. There is always a temperature discontinuity of some degree coincident with the salicline. Usually there is a small negative (decreasing) temperature gradient; however, there were positive (increasing) gradients in the northern part of the area in 1950, and in the southern part in 1951. In some cases these amounted to more than a degree Centigrade and were stable in the presence of large salinity gradients.

Beneath the salicline and extending to the maximum depth sampled, is the lower zone, where both the temperature and salinity gradients show marked regularity. In fact they fitted the logarithmic structure suggested by Tully (1953) within the limits of observations.

As shown in Figure 3 the surface salinity is lowest at the coast and increases seaward throughout the area, and in all seasons. The lowest salinities appear to be associated with Juan de Fuca Strait, and Queen Charlotte Sound, and suggest outflows of coastal waters. The runoff from the land is a substantial factor in reducing the salinity of the surface zone. Even in March when the offshore region was essentially homogeneous to 100 metres depth, appreciable gradients were observed near the coast. Along Vancouver Island the local runoff is a maximum in the winter (Pickard and McLeod, 1953). However, the greatest runoff from the coast as a whole occurs in June, when the large mainland rivers flood due to melting snow in the mountains. Following these floods the fresh water influence is a maximum and extends far offshore. More detailed investigation immediately adjacent to the land would undoubtedly reveal a complex series of systems, varying with tide, as well as the local runoff and discharges from the major drainage systems.

In the offshore region the salinity was relatively constant during each survey, but changed significantly from summer to winter. In the summer, the fresher waters tend to be conserved near the surface, hence the salinity is less than in the winter when the waters are mixed to great depth by the violent storms. In this region the vertical salinity gradient is small at all times, but tends to be greater in summer than in winter. The summer gradients are presumably due to the great precipitation in this area, and are preserved under conditions of strong thermal stability.

The surface temperatures observed during the four cruises are shown in Figure 4. During the summer the water along the coast is cold, particularly in the approaches to Juan de Fuca Strait. This cold coastal belt corresponds to the region of fresh water influence shown in the previous figure. The temperature of the surface zone increases to seaward.

In August 1950 there were several clouds of warm water lying in a band extending due south from the Queen Charlotte Islands and becoming warmer towards the southern limit of the area. Thus the coldest and warmest regions were contiguous. West of the warm belt the water became colder in all latitudes, the minimum temperatures being similar to those in the approaches to Juan de Fuca Strait.

In August 1951 the characteristic band of cold coastal water was again present, and the temperatures increased to seaward. However, in the offshore regions the isotherms crossed the area essentially normal to the coast. The principal gradient instead of being east-west as in the previous year, was practically north-south. Although the average temperature was two degrees higher in 1951, the range was smaller. This picture is a distinctly different type of situation from that observed in the previous year.

It is interesting to note in passing that during August 1950 vast numbers of *vellela* were observed throughout the entire areas of this survey west of Longitude 130°W. Large numbers were visible at all times, and they frequently occurred in such concentrations as to look like great streaks of foam on the water. By the crudest of calculations it was estimated that the number in the area between Longitude 141°W and the coast would be of the order of 10^{10} to 10^{12}, and it is not known how much further they extended in all directions. In August 1951, on the other hand, when the water was warmer, not a single specimen was observed throughout the cruise.

In winter the warmest water was along the shore, and became colder to seaward. It appears likely that this condition is typical of winter and spring.

The dynamic topographies of the sea surface shown in Figure 5 indicate that the currents are weak and variable. In the summer the currents do not exceed two miles a day (4 cm./sec.). They are so sinuous that there appears to be no resolution of flow in the southern part of the area. However, there is a general tendency for water to enter from the south and west, and leave to the north. This results in some degree of convergence and acceleration towards the northern limit of the area. The two August and the May surveys were made during periods of northwest winds which oppose and retard the net flow. The northward tendency is much stronger in the winter (March

1952), attaining four miles a day (8 to 10 cm./sec.). This flow was accelerated by southeast winds, which are dominant in winter.

In the study of the data it was found that the currents decreased with depth to about half the surface value at 300 metres. Below this depth there was little or no intrusion of water from the west, so that there was only a slow northward movement.

It was considered instructive to examine the data by the method of isentropic analysis (Rossby, 1936; Montgomery, 1938), which does not assume gradient flow. However, it was kept in mind that the process of vertical mixing, which would limit the validity of this approach, is likely to be strongest near the coast. The principal patterns of flow suggested by the isentropic charts was similar to those shown by the calculated dynamic topography, although considerable differences in detail were overlooked. However, there was no more definition of flow in these isentropic analyses than in the gradient studies. It was evident that in the summer the area was dominated by eddies or very slow indeterminate movements, with no more than a general tendency northward.

When surface waters are carried seaward by winds from the northwest they are replaced in part by the upwelling of deep waters along the coast. This upwelling has been advanced by a number of authors as an explanation of the cold saline waters found along this coast in the upper zone, during the summer (Igelsrud *et al.*, 1936; Tully, 1938; Pickard and McLeod, 1953) and by Sverdrup (1941), who observed similar phenomena along the California coast.

Figure 6 shows the disposition of isotherms and isosalines along a line normal to the coast of Vancouver Island, during each of the surveys. The March 1952 cruise followed a period of fairly strong variable winds which were predominantly southeast. There is no indication of upwelling associated with these data. The other three cruises were preceded by predominantly northwest winds, and show a distinct rise of the isotherms and isosalines adjacent to the coast. This tendency is most marked in August 1951, when the northwest winds were most prolonged and consistent.

In the classical example of upwelling found off California, the offshore movement of the waters results in the accumulation of light surface water in a narrow stream parallel to the coast, and some distance from it. Off the British Columbia coast the northwest winds oppose the prevailing current and no coastal stream is developed. However, the offshore tendency persists and results in a degree of upwelling. As the water upwells in summer it is diluted by coastal drainage, warmed by insolation, and dispersed in a narrow north flowing coastwise current which has been described by Tully (1938). This current loses

water to the coastal region because of the offshore component of the summer winds. This seaward transport is evidently greater than the supply from runoff so that there is a degree of upwelling. This results in a band of cold water along the coast, which would be as saline as the California coastal water, if it were not diluted by the great summer runoff.

In the winter the prevailing southeast winds impart an onshore component to the motion, the light water is confined in a narrow region close to the coast, and the surface waters are depressed. This is evidenced in the accumulation of low salinity warmer water along the coast at this time. The seasonal effect is noticeable here in that the coastal water, although warmer than that to seaward, is colder than during the summer.

Origins and Circulation of the Water

The general circulation system of the north Pacific Ocean (Figure 7) has long been established by the Pilot Charts of the U.S. Hydrographic Office. The west wind current, called the Sub-Arctic Current by Sverdrup (1942) is the wind driven drift of surface water eastward across the Pacific Ocean between Latitudes 40° and 50°N. As this current approaches the coast of North America it divides. Part turns north to form the Alaska Gyral, and part turns south to form the California Current.

The Marine Life Research Program from Scripps Institution of Oceanography has been studying the California Current in a series of near-monthly cruises since 1949. Fortunately their Cruise 17 coincided with the August 1950 survey and it was possible to combine the dynamic charts as shown in Figure 8. This chart covers an enormous area, and is the first dynamic picture of the current system off the North American coast. It is a spectacular confirmation of the previous conclusions from the Pilot Charts.

It is regretted that the other surveys by both agencies were not coordinated more closely so that a seasonal, and annual series of such diagrams could have been prepared. However, this example shows the position of the area of the present studies in relation to the whole current system, and allows the interpretation of the observations on a broad basis.

Evidently the area off the coast of British Columbia is in the region of the divergence. Because of this, it is a region of eddies, or slow and indefinite currents. Furthermore, it is extremely sensitive to small changes in the route of the trans-ocean current. It may be subject to

northern or southern flow as the point of division of the major current shifts south or north.

Previous studies in the northeast Pacific Ocean have examined small parts of the system. The U.S.S. Bushnell (Sverdrup *et al.*, 1942) crossed the Sub-Arctic Current from the Aleutians to Hawaii. U.S.S. Oglala (Goodman and Thompson, 1940) crossed from the Aleutians to Juan de Fuca Strait. The International Salmon Commission (McEwen *et al.*, 1930) examined three sections normal to the coast in the Gulf of Alaska. Each of these studies shows part of the general picture. When they are considered together it is evident that there is a continuous circulation of low salinity coastal water, in a counterclockwise direction all around the Gulf. Part of this stream is dissipated through the Aleutian Islands into the Bering Sea and the remainder moves southwards to join the continent-bound Sub-Arctic Current. The low salinity surface zone water found throughout the Gulf of Alaska is probably due to the conservation and re-circulation of a substantial part of the coastal water, as well as to the high precipitation associated with the semi-permanent Aleutian low pressure area.

Thompson and Van Cleve (1936) have deduced from drift bottle experiments that in March 1932 the division of the Sub-Arctic Current to form the Alaska Gyral and the California Current occurred well south of Latitude 47°N. They point out that this conforms to the latitude of the division between residual winds, with a northerly and southerly component, as calculated from the Pilot Charts. The resulting current along the British Columbia coast in the winter agrees well with this.

From drift bottle experiments during the summer of 1931, Thompson and Van Cleve concluded that the division of the currents occurred further north at Latitude 50°N, which again agrees well with the division of winds deduced from the Pilot Charts. This conclusion is also supported by Tully's (1938) examination of the waters within 100 miles of Vancouver Island in 1936. These indicated that the general flow was southeasterly and suggest that the division of the great current was north of Latitude 50°N in that summer. These early observations appear to contradict the findings of the 1950 and 1951 studies where the general movement appears to be northward. However, when these are viewed as part of the overall picture (Figure 8) it is evident that there is no contradiction. The southward movement occurs near the coast of Vancouver Island, while the northward tendency is further offshore, and becomes stronger to northward.

These earlier studies are not complete enough to describe the character and location of the great divergence with any precision, and

it cannot be determined whether there are significant differences between them and the present surveys.

However, it is evident that there are important differences between the conditions observed in 1950 and 1951 (Figure 5). The calculated gradients and isentropic analyses suggest that the division of the Sub-Arctic Current was further south in 1951. An attempt was made to relate this difference with the atmospheric pressure systems in the area. However, these showed that the division between the winds with a southerly component and those with a residual northerly component was further south in 1950. Thus the differences between these two years observations are not immediately apparent in the wind fields.

Considering the character and magnitude of the system (Figure 8) it may be anticipated that the division of currents will shift north and south by several degrees of latitude from year to year. Such changes are small, but their effect is enormous in the strategic area off the British Columbia coast. It cannot be said that the early data showing a southward flow near the shore are inconsistent with the present data indicating a northward movement further offshore, or that the change of character of the currents and properties from year to year are anomalous. The present problem is to determine the cause, sequence, and nature of these changes.

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LIST OF FIGURES

FIG. 1.—Chart of the offshore waters of the Canadian Pacific Coast showing the courses sailed, and the stations occupied in May and August, 1951. Observations were made along approximately the same lines in the other cruises, although the arrangement and numeration of the stations were different.

FIG. 2.—Examples of the characteristic temperature and salinity structure in the offshore region, off the Pacific Coast of Canada, at Latitude 50°N, Longitude 135°W (c.f. Figure 1).

FIG. 3.—Surface salinity observed off the Pacific Coast of Canada.

FIG. 4.—Surface temperatures observed off the Pacific Coast of Canada.

FIG. 5.—Calculated geopotential topography of the sea surface (anomaly of dynamic height, metres) and implied gradient currents. Arrows indicate the direction of flow. The inset diagram shows the current speed in relation to the distance between isobars.

FIG. 6.—Structure of the water off the Pacific Coast of Canada. Vertical sections showing the distribution of temperature (°C light lines) and salinity (S $^{o}/_{oo}$ heavy lines) as observed on line A, normal to the coast of Vancouver Island during each o fthe four cruises. The location of the section is shown in Figure 1.

FIG. 7.—Schematic diagram of the surface zone circulation in the northeast Pacific Ocean.

FIG. 8.—Anomaly of dynamic height (metres) from the August, 1950 survey of the Pacific Oceanographic Group, and Cruise 17 of the Marine Life Research Program (Scripps, 1951).

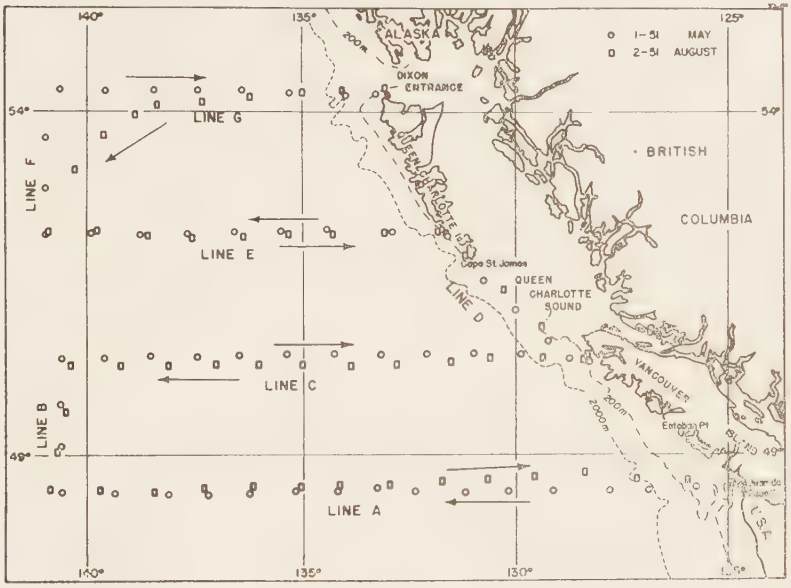

FIGURE 1

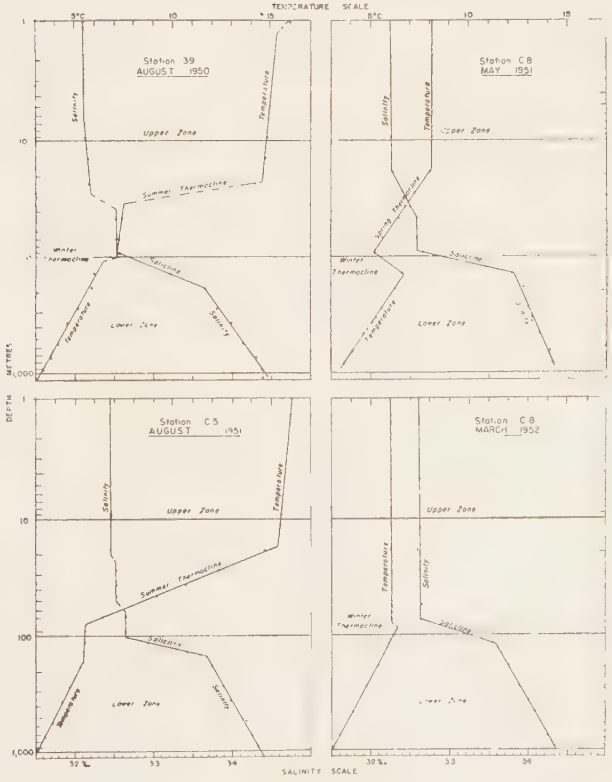

FIGURE 2

FIGURE 3

FIGURE 4

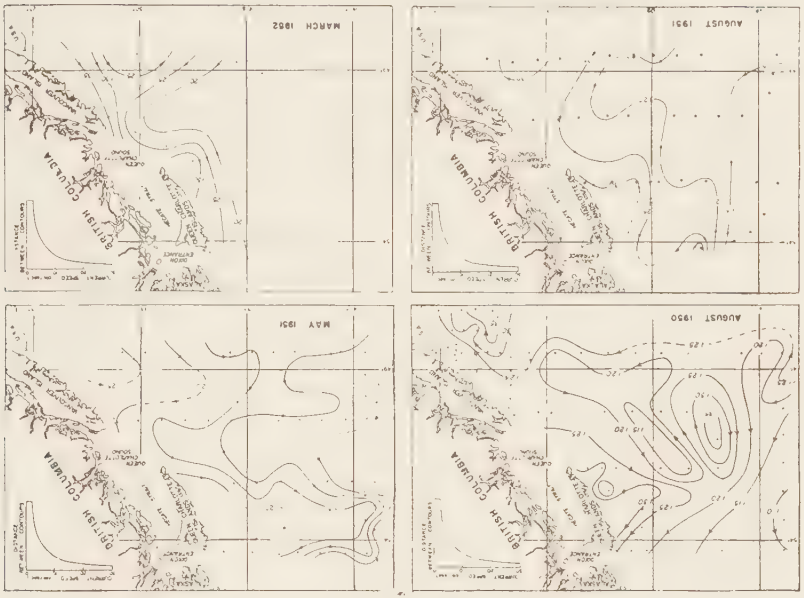

FIGURE 5

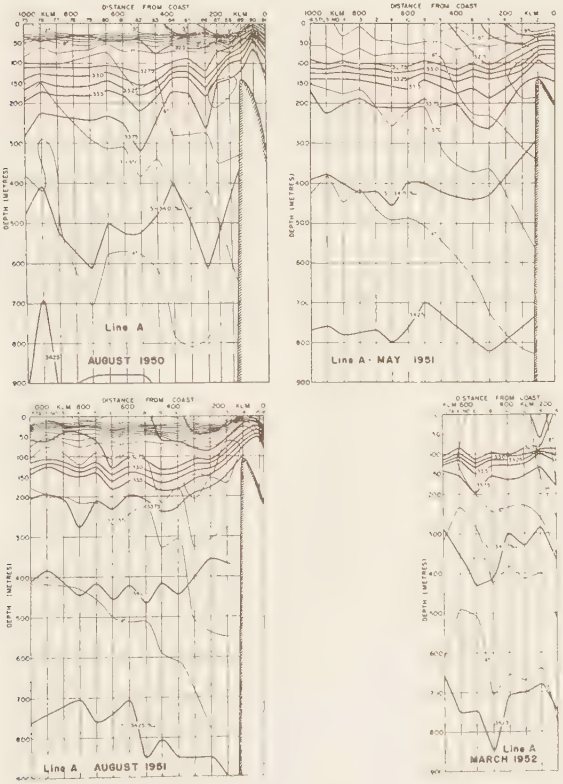

FIGURE 6

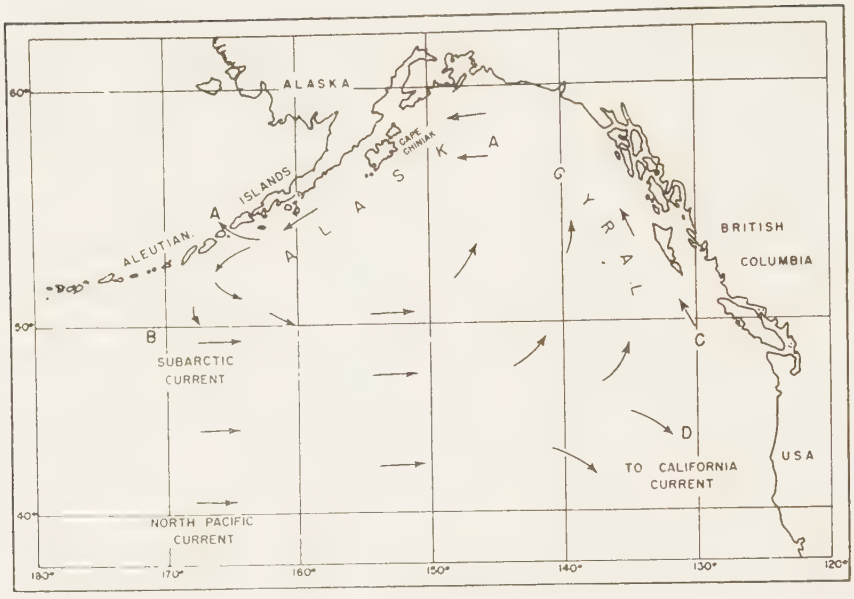

FIGURE 7

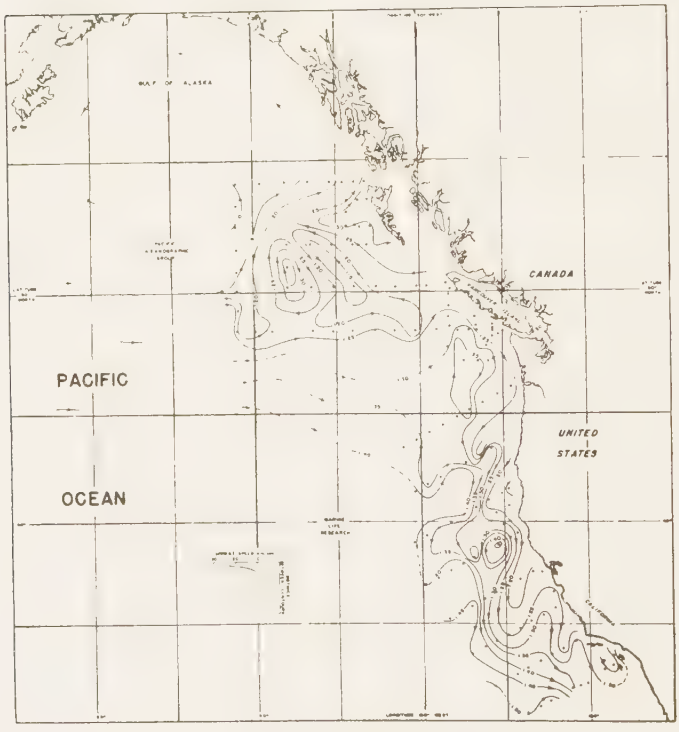

FIGURE 8

CIRCULATION NEAR THE WASHINGTON COAST *

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Introduction

The area covered in this paper is a section of the Northeast Pacific Ocean bordering the West Coast of North America between the parallels of 44° and 51° North and extending 600 miles seaward (Fig. 1). The coast is mountainous and contributes considerable runoff to the sea from heavy precipitation in winter and the melting of the snow in early summer. Two concentrated sources of fresh water are the Strait of Juan de Fuca and the Columbia River, which drain large inland areas. The Strait differs markedly from the river in that it is the mouth of a large tidal basin and is deeper than 100 fathoms for a considerable distance inshore. As a result of the tidal action, its effluent has been considerably altered by mixing with the cold deeper water.

The continental shelf, as measured by the 100-fathom contour, extends about 40 miles offshore near the Strait of Juan de Fuca and narrows to about 20 miles both northward and southward. Beyond the slope, depths increase gradually to about 2000 fathoms. A number of seamounts rise from this deeper water, but the bathymetry of only a few has been worked out in any detail.

The climate of the region is predominantly maritime with prevailing southwesterly onshore winds accompanied by heavy precipitation from autumn to spring. In summer considerable air flow is from the northwest and north and little precipitation occurs.

The circulation of the Northeast Pacific is predominantly clockwise to latitude 40° North, giving way to counterclockwise south of 30 North (Sverdrup, Johnson and Fleming, 1946). The colder water along the northern periphery of the main easterly drift in mid-ocean, the so-called Aleutian or Subarctic Current, splits in all ill-defined zone well seaward from the coast near 45° North, both orientation and position of the zone of divergence varying with the season. The northerly arm, the Alaska Current, recurves through the Gulf of Alaska; and the southerly arm, the California Current, sets south well offshore at lower lati-

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tudes. Off the Washington and Oregon Coasts in winter, the Davidson Current feeds water northward inshore. The area studied, being an area of divergence, is characterized by weak and poorly defined currents which are easily influenced by temporally changing wind patterns and local bathymetric irregularities.

The measurements to be reported in this paper were carried out with the research vessel M. V. BROWN BEAR during seven offshore cruises in the spring and summer months of 1952 and 1953. Because of the anticipated variations of currents with time, determinations of circulation patterns by dynamic topographies were supplemented by use of the Geomagnetic-Electro-Kinetograph (G.E.K.). It was quickly discovered that the latter instrument was measuring currents (or effects) very much greater than those from dynamic topographies, and showing a rotary variation with time. In recent cruises therefore, several time studies have been made to discover the nature of the rotary variations.

Further evidence of the reality of the rotary variations was obtained by direct current measurements from an anchor station on Cobb Seamount, a seamount rising very sharply from 1500 fathoms depth to within 16 fathoms of the surface, and located approximately 270 miles west of the Washington Coast (46°–45.5′N, 130°–46.3′W). The results from two such time studies are presented in some detail.

Another sphere of activity has been a detailed investigation of the outflows of the Strait of Juan de Fuca and the Columbia River, particularly the latter. The outflow of the Columbia has been traced for over 200 miles seaward. The position and structure of this long plume of less saline water is of interest as an indicator of offshore circulation and mixing, and because of the possible influence it may exert in directing the salmon which migrate to and from the river.

The circulation near the coast of Vancouver Island and the mouth of the Strait of Juan de Fuca has been discussed by Tully (1938, 1941) on the basis of salinities and temperatures measured near the coast, often in shallow water. These measurements as well as those of Marmer (1926) made from Swiftsure Lightship establish the direction of outflow of the Strait of Juan de Fuca as northwestward, very close and parallel to the coast of Vancouver Island. Tully further shows the accumulation of fresh water along the coast due to the prevailing southwesterly winds in spring and early summer, with a gradual transition to a condition of upwelling in a narrow band along the coast under influence of the northerly winds of late summer. He interprets the resulting dynamic topographies as representing northwesterly flows close to the coast in early summer and a reversal in direction in late summer. The latter flow, however, is overcome by the generally northwesterly

outflow of the Strait of Juan de Fuca near the mouth of the Strait. Similar conclusions as to the seasonal shift in currents were reached by Thompson and Van Cleve (1936) from drift bottle experiments commenced about 80 miles off the Canadian Coast. These authors also relate the change in direction of flow during the summer to a change in wind pattern. Some dynamic sections along the coasts of Washington and Oregon are presented by Sands (1937), but these are too few in number and too close to shore to correlate with the present work.

Farther offshore, the circulation off the Canadian Coast has been studied by Doe (1952) and Goodman and Thompson (1940) in two sections, from the Strait of Juan de Fuca to Dutch Harbor, and from the Strait of Juan de Fuca to Hawaii. Still farther offshore, the Carnegie Cruise VII (Fleming, 1945) established the gross structure of the eastward flowing Aleutian Current and the beginning of its separation into southeasterly and northeasterly branches. Two or more sections have also been made by Scripps Institution of Oceanography, the U. S. Fish and Wildlife Service, and the U. S. Navy Electronics Laboratory, but the results are unpublished. To the south, Scripps Institution of Oceanography have studied the coastal currents very intensively and their cruises have occasionally come as far north as the Columbia River. Thus the details of the circulation near the Washington Coast are little known.

With respect to the G.E.K., as used in areas of weak and poorly defined currents such as this, there is little published. The interpretation of the results as currents is in some question, as is the "K" factor. The apparently rotary current changes observed, although indicated by von Arx (1950), have not been carefully analyzed, probably because in areas of high currents they are relatively less important. Oceanographers at Scripps Institution of Oceanography are known to be working on this problem. For analysis of the rotary current changes in the deep sea, one must turn to the direct measurements made from anchored vessels, the BLAKE in West Indian waters (Pillsbury, 1891), the MICHAEL SARS (Helland-Hansen, 1930), the METEOR (Defant, 1932), the ALTAIR (Defant, 1940), and the ARMAUER HANSEN (Ekman, 1953). In all of these, the uncertainties due to the motion of the anchored vessels weaken the validity of the conclusions. However, rotary current changes do occur and these changes apparently contain components of tidal and inertial periods as well as random fluctuations. The existence of rotary currents of tidal period in shallower water is well established, and Gustafson and Kullenberg (1936) have demonstrated an excellent example of inertial rotations in the Baltic.

Water Properties and Circulation

As others have suggested, the horizontal gradients of temperature and salinity may be generalized in two representations, one for spring and early summer and one for late summer. The winter conditions have not been studied. Figures 2 and 3 show the horizontal distribution of surface temperature and surface salinity in April–May, 1953, the data having been smoothed to eliminate local fluctuations. The piling up of warm surface water along the coast of Vancouver Island is evident.

Figures 4 and 5 show the conditions in July 1952. Here the breakdown of spring conditions is just beginning to appear. The water which earlier increased in temperature essentially up to the coast is now showing a wide band of somewhat cooler water near the coast. The effect is more marked if vertical sections of temperature are plotted, demonstrating the decrease in thickness of the surface water layer on approaching the coast. Close to the mouth of the Strait of Juan de Fuca, the effect is accentuated at the surface probably because of the mixing processes of tidal flow as well as the tendency of upwelling deeper water to appear far within the Strait.

Figures 6 and 7 (smoothed somewhat) show the conditions in September 1953, farther south. Although not completely comparable with the above data because of the different areas covered, there is still superficial evidence of upwelling in the region near the mouth of the Strait of Juan de Fuca. Along the Washington Coast south of the Strait, the subsurface temperature structure indicates the presence of upwelling which, however, does not reach the surface because of a blanketing layer of less saline water. This is especially so in the vicinity of the Columbia River mouth where the surface waters flowing seaward are rapidly replaced by river effluent. Along the Oregon Coast south of the Columbia, low temperatures characteristic of upwelling are again apparent at the surface.

Figures 6 and 7 also show the first results of a detailed study of the Columbia River outflow. The plume of water having a salinity less than $32.0^{o}/_{oo}$ is seen to extend over 200 miles to the southwest. Associated with the lower salinity is a somewhat higher temperature. The position of the wake stream is in itself evidence of the generally southerly set of the currents in this region during the summer. At the velocities indicated by the dynamic topography for the general area, the time required for the water to travel to the outer limits of the $32^{o}/_{oo}$ isosal is of the order of one to two months, and hence the position of this limit establishes a minimum value for the integrated currents for at least this period.

The processes of mixing in the wake stream have not yet been examined. However, there is some interest attached to the abrupt change in salinity gradient seaward of the $31.0^{0}/_{00}$ isosal. In essentially all of the area between this and the next isosal, the surface salinities are greater than $31.5^{0}/_{00}$ and mostly greater than $31.7^{0}/_{00}$.

The dynamic topographies within 300 miles of the coast have been quite consistent in all the cruises analyzed. Since only Cruise No. 7 in July 1952, went as far offshore as 600 miles, data from this cruise are combined with a composite of all the others to obtain a generalized diagram for the area which is presented as Figure 8. The curves south of 46°–30′ are based principally upon data from Cruise No. 9 in early September 1952.

Appearing generally in all cruises are the lower dynamic heights to the west of about 130°W, corresponding to northerly or northeasterly flows of 5 cm/sec or less. Some changes in gradient occur in different months but the general picture is little altered except that the contours seem to tend more nearly northward in the early summer, as would be expected from the meteorological conditions. Also appearing in all the data is evidence for a deflection southward of northeasterly flowing streamlines in the area between 128° and 130°W and 47° to 49°–30′N. The data of Cruise No. 9 indicate that this flow continues southward along the Washington Coast and is probably responsible for carrying the Columbia River water southward. These results are consistent with those of Doe (1952).

G.E.K. Results and Time Studies

Early in the investigations, it was discovered that apparent currents measured hourly by means of the G.E.K. along a cruise track showed continual changes in direction and magnitude, suggesting the rotary changes of tidal period observed at lightships. These currents typically had peak values of 15–20 cm/sec and occasionally as high as 35 cm/sec, the correction factor "K" for the G.E.K. being taken as unity. To be contrasted with these are the velocities below 5 cm/sec, determined from the dynamic heights. Tidal periods could be found in the data by harmonic analysis, but the amplitudes were only about one-fifth as great as the observed peaks. Later it was discovered that inertial periods were present, with amplitudes of the same magnitude or somewhat greater than those of tidal period. The inertial period in this area is approximately 16 hours. The harmonic analyses of these data were interpreted with some reservations due to the fact that the ship was rapidly changing position and to the evident existence of apparently random fluctuations of considerable magnitude.

In order to derive the residual non-fluctuating currents in this situation, the data have been calculated as 48-hour running means, 48 hours being the least common multiple of 16 and 12 hours. If tidal and inertial constituents are present, they should disappear in the averages together with the greater part of those of shorter and random periods. This is admittedly a rather brutal treatment, as any fluctuations in the residual current are severely smoothed thereby. However, it has served for the preliminary investigations.

A serious disadvantage is the fact that the ends of a continuous series of observations may be approached within only 24 hours by averaged results, and hence any lengthy break in continuity of the data may leave large gaps in the results. Twenty-four hour groupings also have been tried and are found to remove most of the fluctuations and leave smaller gaps. It is preferred to use 48-hour means where possible, however, since the results will be less ambiguous.

The results of such a treatment to the data of Cruise No. 7 are shown in Figure 9. The large gap in the data on the northern leg of the cruise is due to the break in continuity occasioned by a short storm. Twenty-four hour means, however, show the residual currents setting south to southwest throughout most of the northern leg, with velocities of the order of 5 to 8 cm/sec. A comparison with Figure 8 shows some similarity of G.E.K. means to the dynamic heights along 48°–30′N but none whatsoever along 50°–30′N. The current pattern is also internally inconsistent, requiring the existence of a region of convergence within the area surveyed, an improbable situation. It appears evident therefore that the G.E.K., in this region, does not always measure the long-term average flows associated with the distribution of mass. The converse might be true in regions where stronger currents are found.

It is postulated therefore that the currents measured are shallow wind-driven currents of short duration. To test this hypothesis, average wind vectors have been plotted along the course. There is reasonable correspondence along 48°–30′, assuming the resulting flow to be 45° to the right of the wind and lagging it by a few hours. In the northwest corner of the survey, there appears to be an inconsistency. However, the northwest storm which appeared two days later at about 130°W longitude may already have been driving water well ahead of it. Along 50°–30′, the agreement with 24-hour average currents (not shown) is good.

These results showed the necessity of making time studies with the G.E.K. The first studies begun in June 1952, were about one day in length and were made by steaming back and forth over an 8-to-16-mile course, obtaining G.E.K. fixes enroute. Hydrographic stations to 1,000

meters of depth were occupied at intervals of 2 to 12 hours in the several experiments in an attempt to correlate the results with the dynamic heights. Rotary changes in current direction were readily demonstrated, but twenty-four-hour periods are too short for effective harmonic analysis. Two experiments of 3 to 4 days' duration were therefore made in June and August 1953, Cruises No. 29 and 31, respectively.

In Cruise No. 29, the ship steamed backward and forward two hours' run on reciprocal headings, taking G.E.K. fixes every hour together with other data. Positions were fixed frequently by loran, and hydrographic stations were occupied about every 12 hours. Some failures in equipment being used for corollary measurements caused several undesirably large gaps in the data, but the results are only a little less consistent than those to be presented below.

In Cruise No. 31 the cruising plan was modified, as suggested by Mr. Joseph Reid of Scripps Institution of Oceanography, so that the ship steamed squares on the cardinal compass headings, each side being approximately 7 minutes' run. Thus a fix is obtained every 7 minutes, there being some interdependence in the measurements because each datum enters into two fixes and two zero determinations. Reid has directed experiments of this type in which he has simultaneously followed a freely drifting buoy (personal communication). An attempt to do this with an improvised buoy and drag was abandoned after the buoy lost its drag and was itself nearly lost at night during a radar failure.

The results of this experiment have been expressed as north and east components of velocity and are presented in Figure 10. K has been assumed to be unity and corrections have been made for electrode droop. The results are surprisingly consistent and have given rise to a renewed belief in the reality of G.E.K. measurements. The 16-hour inertial period is evident by visual inspection. Much of the distortion is due to other components, principally the semidiurnal. Some smoothing has been practiced but there is difficulty in deciding which fluctuations may be real and which due to experimental uncertainty. Due to the interdependence of separate fixes, errors often appear symmetrically in alternate or adjacent points. Moreover, in some cases the record can not be interpreted more accurately than several tenths of a millivolt.

In correlation with this experiment, an anchor station was occupied for the preceding three and one-half days atop Cobb Seamount (see Fig. 8). Here currents were measured at a depth of 20 meters with an Ekman current meter every 30 minutes, and temperature structures were measured hourly by bathythermograph. Bathythermograms were

also obtained hourly during the time study with the G.E.K. Three hydrographic stations were occupied at corners of a 30-mile square about the seamount to obtain dynamic heights for comparison. The time study with the G.E.K. was performed in depths ranging from 1,500 to 600 fathoms and between 30 and 15 miles northwest of the seamount. The ship drifted south during the period.

The direct current measurements also show rotary changes containing tidal and inertial components. The basic periods are less well defined because of the motions of the ship, but these motions are small compared to those of a ship anchored in deep water. It is assumed in these two experiments that there should be some similarity in the currents on a sharp isolated seamount to those in the adjacent deep water. On the other hand, considerable distortion near the seamount would not be surprising.

The results of harmonic analysis are given in Table I, for both the direct measurements and the G.E.K. Only the 16- and 12-hour components are considered of primary importance, but the higher harmonics are presented to suggest the magnitude of the amplitudes which could result from random data in a series of this length. The contribution of each constituent is assumed to be expressed in the form

$$v_n = V_n \cos(\theta - \kappa_1)$$
$$v_e = V_e \cos(\theta - \kappa_2)$$

where v_n and v_e are the instantaneous values of the north and east components of velocity, V_n and V_e are the corresponding amplitudes, θ is the time angle of the constituent and κ_1 and κ_2 are the local epochs, the negative of the conventional phase angle, the origin of time being the time of local lunar transit on the first day of the anchor station.

If $\kappa_2 - \kappa_1$ expressed as an angle less than 180° is positive, rotation of the current vector with time is clockwise. In particular, if $\kappa_2 - \kappa_1 = 90°$ and $V_n = V_e$, the current hodogram for the constituent is a circle. Theoretically, circular changes are to be expected in the inertial component and generally elliptical changes in the tidal component.

It is evident that most of the motion is accounted for by inertial and semidiurnal constituents, the former preponderating. The diurnal constituent is probably of significant magnitude, but the others are questionable. The phase difference between north and east components in these three constituents corresponds to clockwise rotations, as would be expected from the deflecting force of the earth's rotation. In the inertial constituent, it is very nearly 90° for both the direct measurements and the G.E.K. In the G.E.K. results, the two amplitudes are essentially the same, which satisfies the condition for circular rotation. Further deductions from the phase relations will be attempted at a

later date. The amplitude of the semidiurnal constituent on Cobb Seamount is about 15 per cent less than the G.E.K. results, which is the same as the change in the mean tidal range at Astoria during the two periods. The change in the inertial component may arise from an increase in average wind velocity from about 8 to 20 knots over the same period.

The results of the time study in June 1953, are shown in Table II. Although the amplitudes are smaller, the relative importance of the 16- and 12-hour constituents is supported. This experiment was carried out at 48°–02′N, 130°–29′W; and by chance during the time study, the ship drifted over and charted a new seamount rising to a least depth of 280 fathoms. This shallowing of the water may have had some effect upon the G.E.K.

The possibility exists that internal waves of tidal and inertial period give rise to the currents or effects measured by the G.E.K. This has been investigated by a study of the bathythermograms taken to a depth of 450 feet during the time study of Cruise No. 31. Internal waves occur with amplitudes of the order of 25 feet but with periods poorly defined. Visual examination suggests six-hour and two-hour periods rather than those of twelve or sixteen hours. It is felt therefore that these internal waves are not a determining influence on the G.E.K. results, but that they possibly account for some of the aberrations and short-period constituents.

In Table III, the average residual current calculated from the three time studies is compared with the dynamic topographies and with the approximate drift of the ship as determined by deviations from the courses run, measured by loran fixes. In Cruise No. 29, the G.E.K. compares well with the drift of the ship but not with the dynamic topographies. This was in a period of light winds in which the ship might be expected to move with the water. In Cruise No. 31, there is little agreement, possibly because the winds averaged 20 knots from the north. However, the direct current measurements compare favorably with the dynamic topographies close to the seamount. Farther away, the velocity and direction derived from the topographies are extremely uncertain and are not shown. It seems well established therefore that the rotary changes observed by the G.E.K. in deep water have their counterpart in the direct measurements of currents.

Conclusions and Summary

The water circulation off the coasts of Vancouver Island, Washington and Oregon in late spring and summer has been studied by means of dynamic topographies and the G.E.K. A picture is presented which

fills a previously existing gap in the information for the central area. The relatively flat dynamic topography is especially sensitive to transient conditions and experimental error. Nevertheless, the topographies consistently show a weak northeasterly circulation at 5 cm/sec or less, part of which is deflected southward off Vancouver Island to continue along the coast past 45° North. This circulation pattern is consistent with previous work in the adjoining areas, and with the assumed divergence of the Aleutian Current beginning well offshore around 45° North.

The G.E.K. has been shown to measure apparent currents which rotate in direction and fluctuate in intensity. The peak flows are of the order of 20–35 cm/sec which is several times greater than the net flows. The rotations contain semidiurnal and inertial constituents, the latter predominating.

A time study in direct measurement of currents on Cobb Seamount, 270 miles offshore, has been compared with a similar time study with the G.E.K. in the adjoining deep water. Harmonic analysis of the North and East components of velocity has produced amplitudes of 7–11 cm/sec for the semidiurnal constituents. The differences could be almost completely accounted for by the change in phase of the moon during the period of the measurements. The amplitudes of the inertial constituent were 9 and 13 cm/sec in one case and 22.5 cm/sec in the other, a difference ascribed to an abrupt change in wind velocity. Another time study with the G.E.K. showed similar results, but smaller amplitudes. The combined results suggest that the currents being measured by the G.E.K. are real. This conclusion is supported by the published results of current measurements at several deep-sea anchor stations which show similar variations.

The net currents obtained by averaging the G.E.K. results show little correspondence with those indicated by dynamic topographies. The former probably represent short-term surface currents due to the wind, whereas the dynamic topographies represent integrated effects over longer periods.

In conclusion, it is suggested that progress in the interpretation of currents in this area requires a better insight into the cause and nature of the transient currents. The G.E.K. should be useful in these studies, but must be further evaluated in terms of direct measurements.

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TABLE I

Harmonic Analyses of Currents
Direct Measurements and G.E.K. Compared

4-11 August 1953

Period, Solar Hours		24.8		16		12.4		8.3		6.2		4.1	
		DIRECT	G.E.K.	DIRECT	G.E.K.	DIRECT	G.E.K.	DIRECT	G.E.K.	DIRECT	G.E.K.	DIRECT	G.E.K.
Amplitude cm/sec	N. Comp.	2.6	3.0	12.6	22.4	6.8	7.6	3.4	1.1	1.3	2.5	0.9	0.8
	E. Comp.	2.6	2.5	9.1	22.6	9.1	10.9	2.0	2.6	0.5	2.3	2.0	1.3
Local Epoch, κ,* in degrees	N. Comp.	167	192	338	14	132	332	319	120	292	109	182	318
	E. Comp.	295	279	68	102	234	85	112	124	78	177	69	157

* The constituents are expressed as cosines, and κ is the positive angle measured from the time of local lunar transit on 4 August to the time of constituent maximum.

TABLE II

HARMONIC ANALYSES OF CURRENTS BY G.E.K.
7-10 June 1953

PERIOD, SOLAR HOURS		24	16	12
Amplitude cm/sec	N. Comp.	2.3	6.4	4.9
	E. Comp.	3.7	5.6	4.8
Local Epoch,* κ, in degrees	N. Comp.	171	154	245
	E. Comp.	234	274	274

* The constituents are expressed as cosines, and κ is the positive angle measured from the time of local lunar transit on 7 June to the time of constituent maximum.

TABLE III

COMPARISON OF NET VELOCITIES BY DIRECT MEASUREMENT, G.E.K., AND DYNAMIC TOPOGRAPHIES

		VELOCITY cm/sec	SET °T
Cruise No. 29			
G.E.K.		6.6	130
Dynamic Topography		3	055
Drift of Ship		5	156
Cruise No. 31			
Direct Measurement		4.5	095
G.E.K.		3.6	270
Dynamic Topography	Cobb Seamount	10	100
	G.E.K. Position	?	?
Drift of Ship		10	173

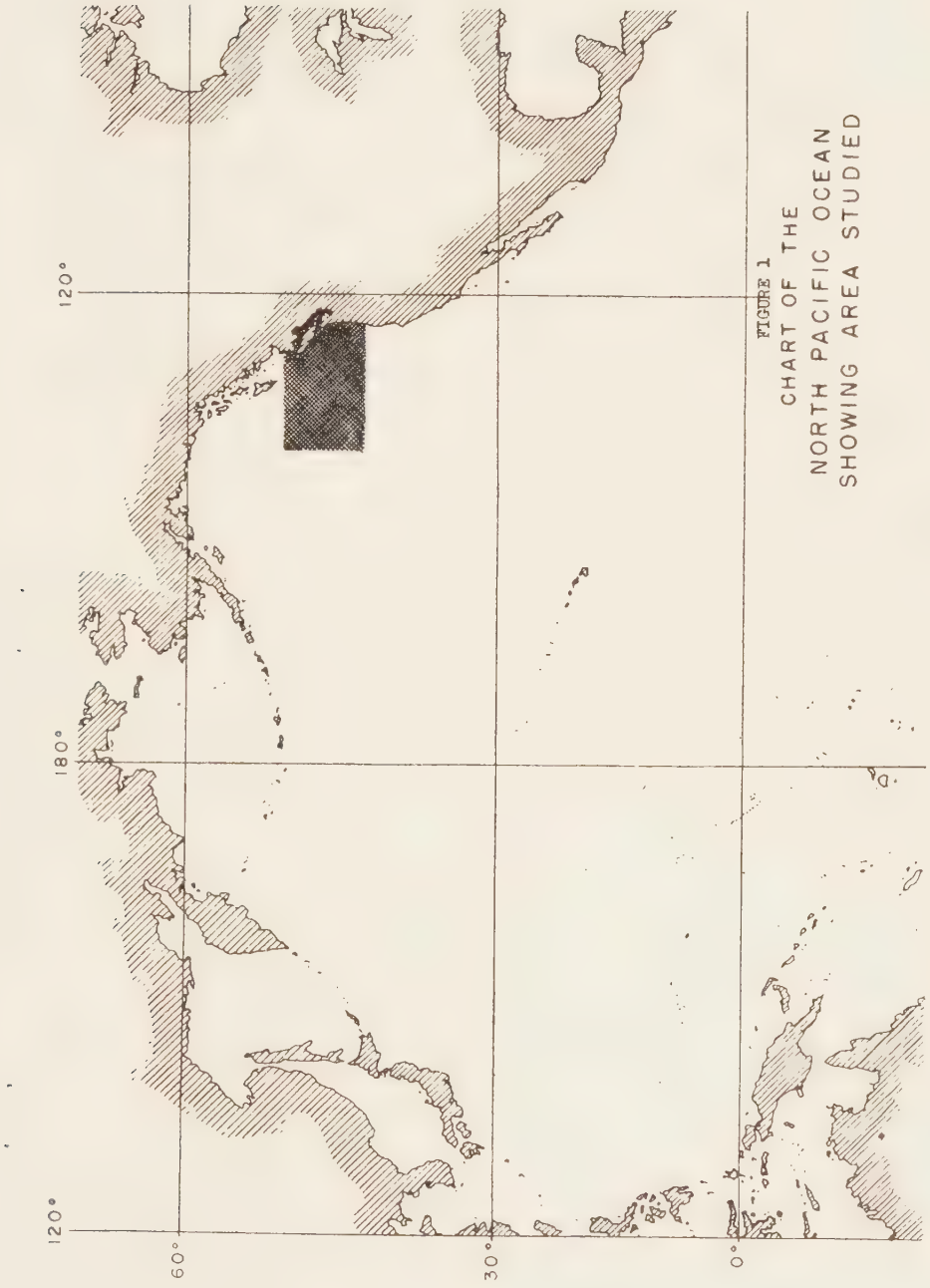
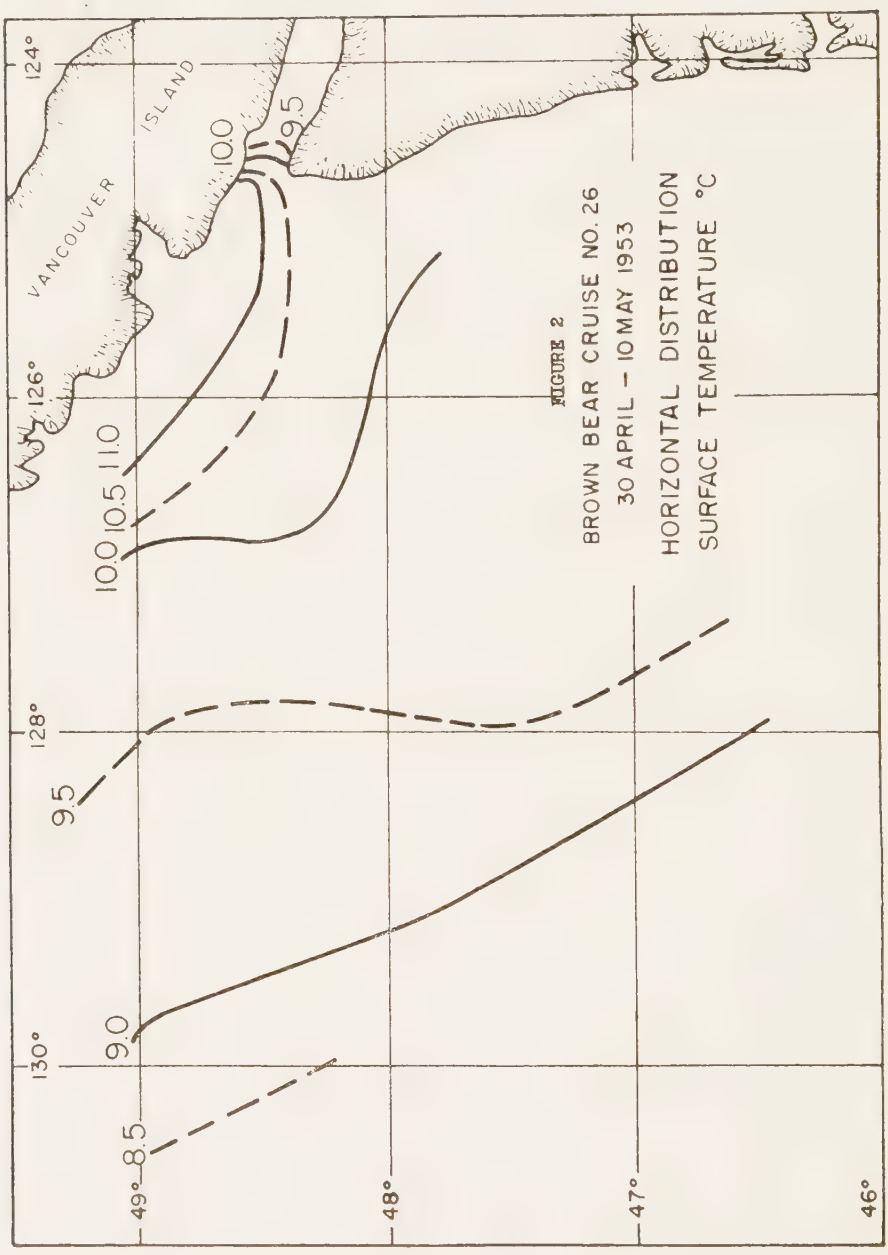


FIGURE 1
CHART OF THE
NORTH PACIFIC OCEAN
SHOWING AREA STUDIED


124°
126°
128°
130°
49°
48°
47°
46°
VANCOUVER ISLAND
10.0
9.5
10.0 10.5 11.0
9.5
9.0
8.5
FIGURE 2
BROWN BEAR CRUISE NO. 26
30 APRIL – 10 MAY 1953
HORIZONTAL DISTRIBUTION
SURFACE TEMPERATURE °C

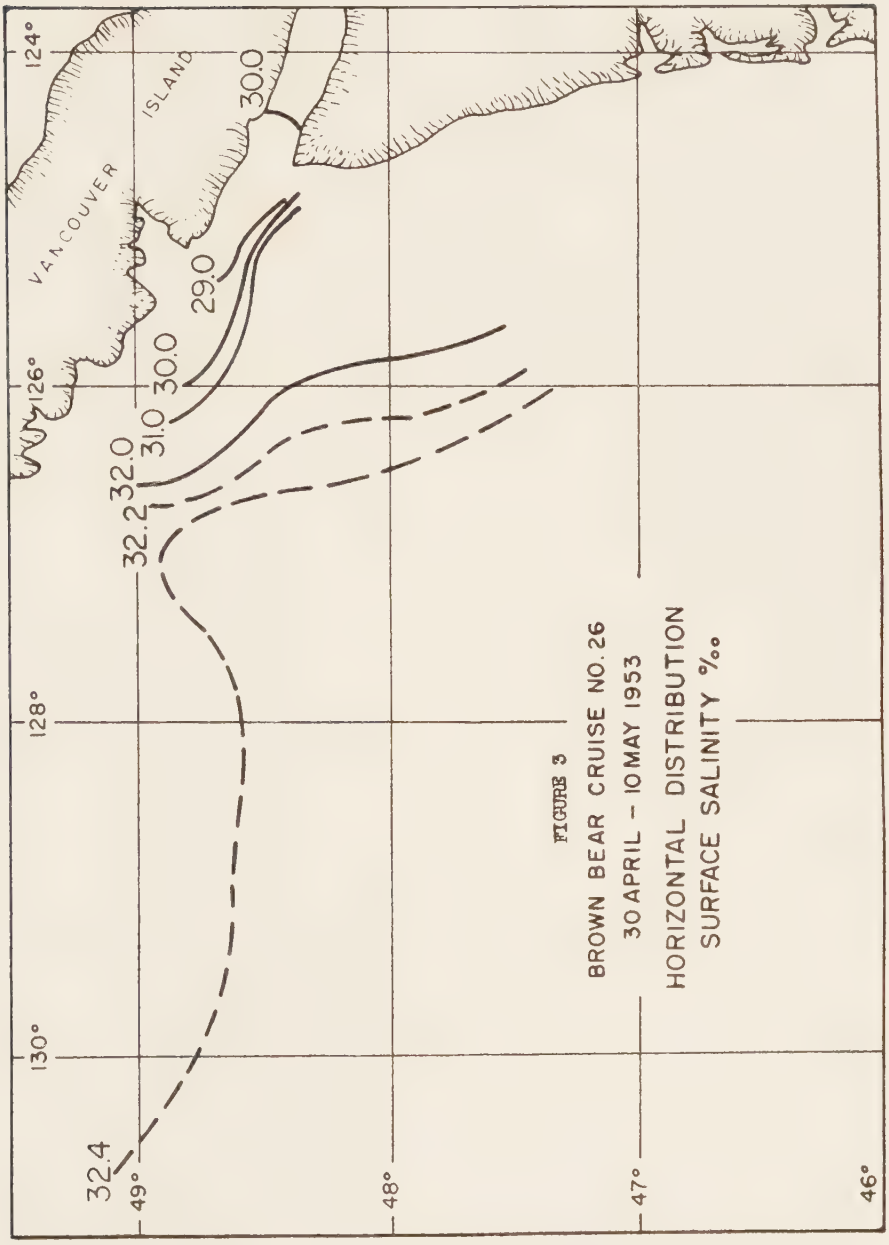


FIGURE 3
BROWN BEAR CRUISE NO. 26
30 APRIL – 10 MAY 1953
HORIZONTAL DISTRIBUTION
SURFACE SALINITY ‰

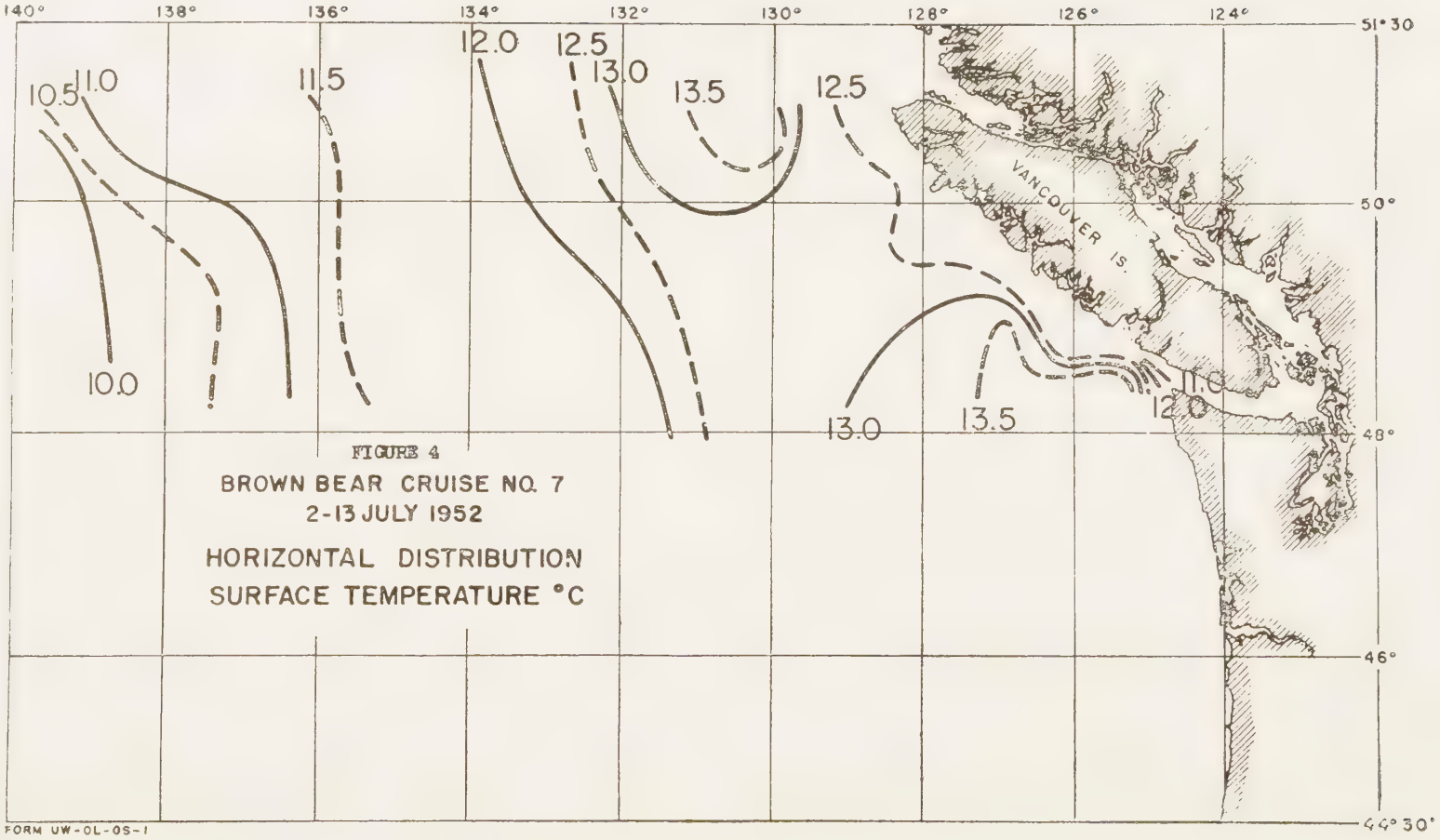


FIGURE 4

BROWN BEAR CRUISE NO. 7
2-13 JULY 1952

HORIZONTAL DISTRIBUTION
SURFACE TEMPERATURE °C

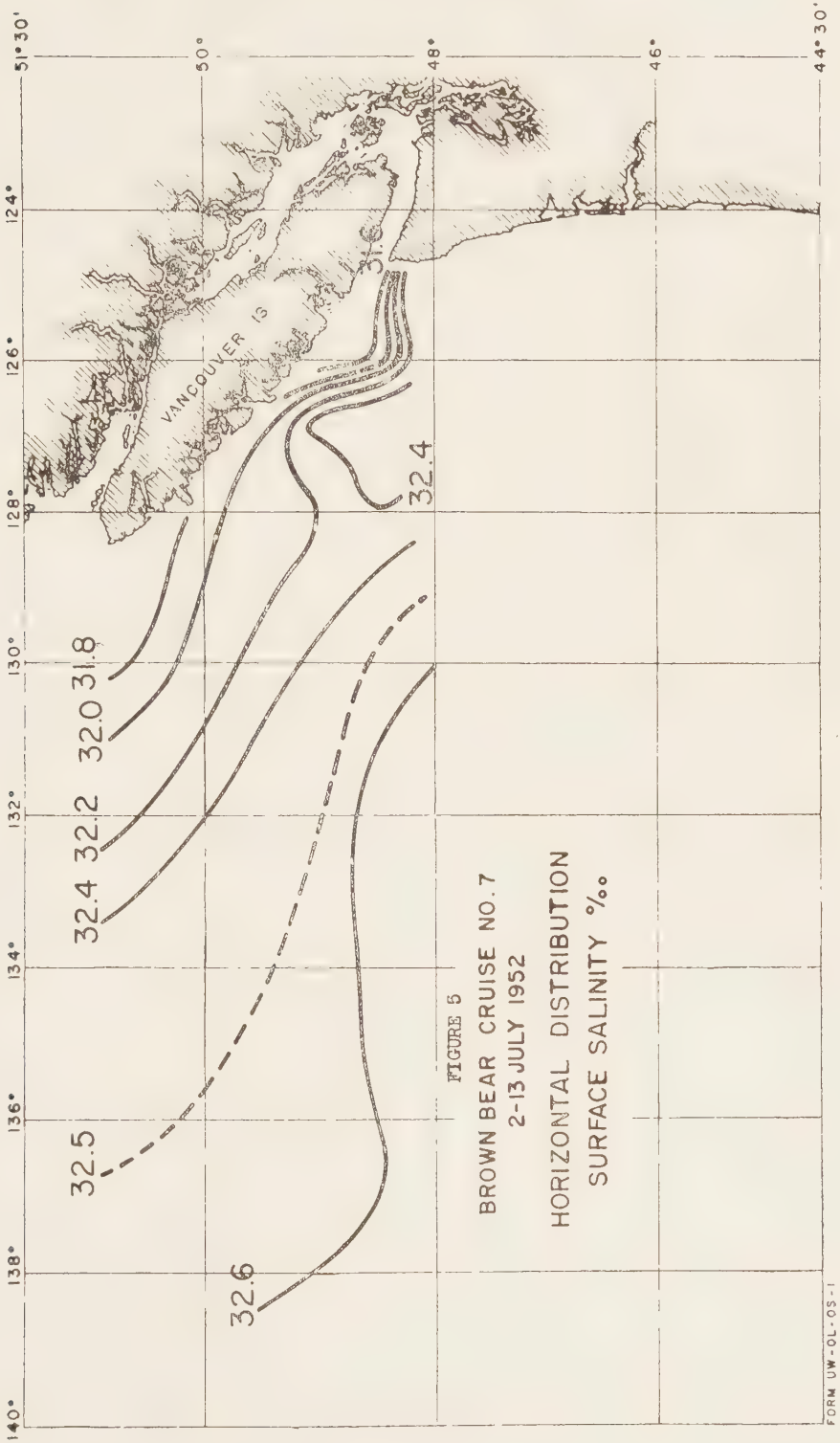


FIGURE 5
BROWN BEAR CRUISE NO. 7
2-13 JULY 1952
HORIZONTAL DISTRIBUTION
SURFACE SALINITY ‰

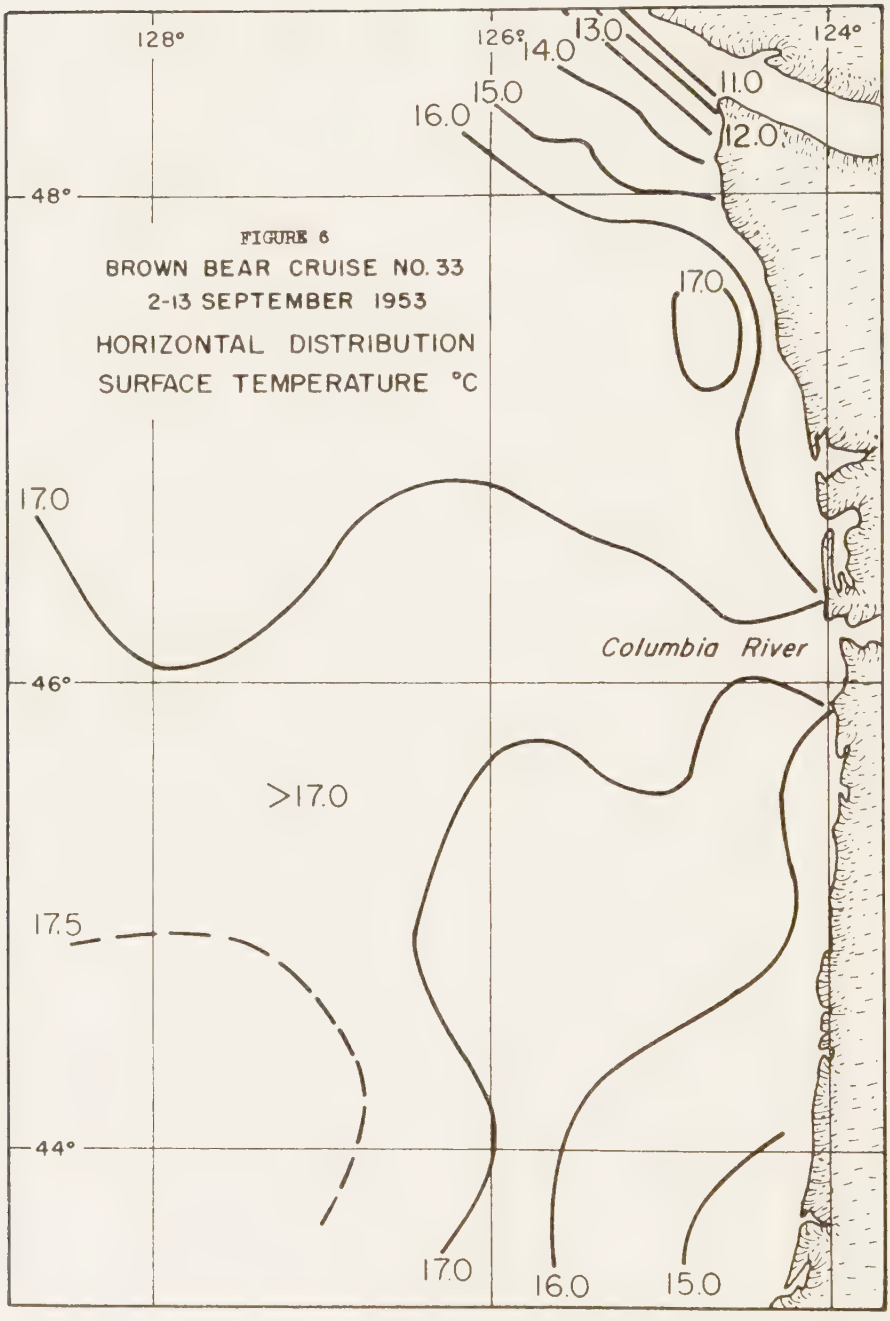


FIGURE 6
BROWN BEAR CRUISE NO. 33
2-13 SEPTEMBER 1953
HORIZONTAL DISTRIBUTION
SURFACE TEMPERATURE °C

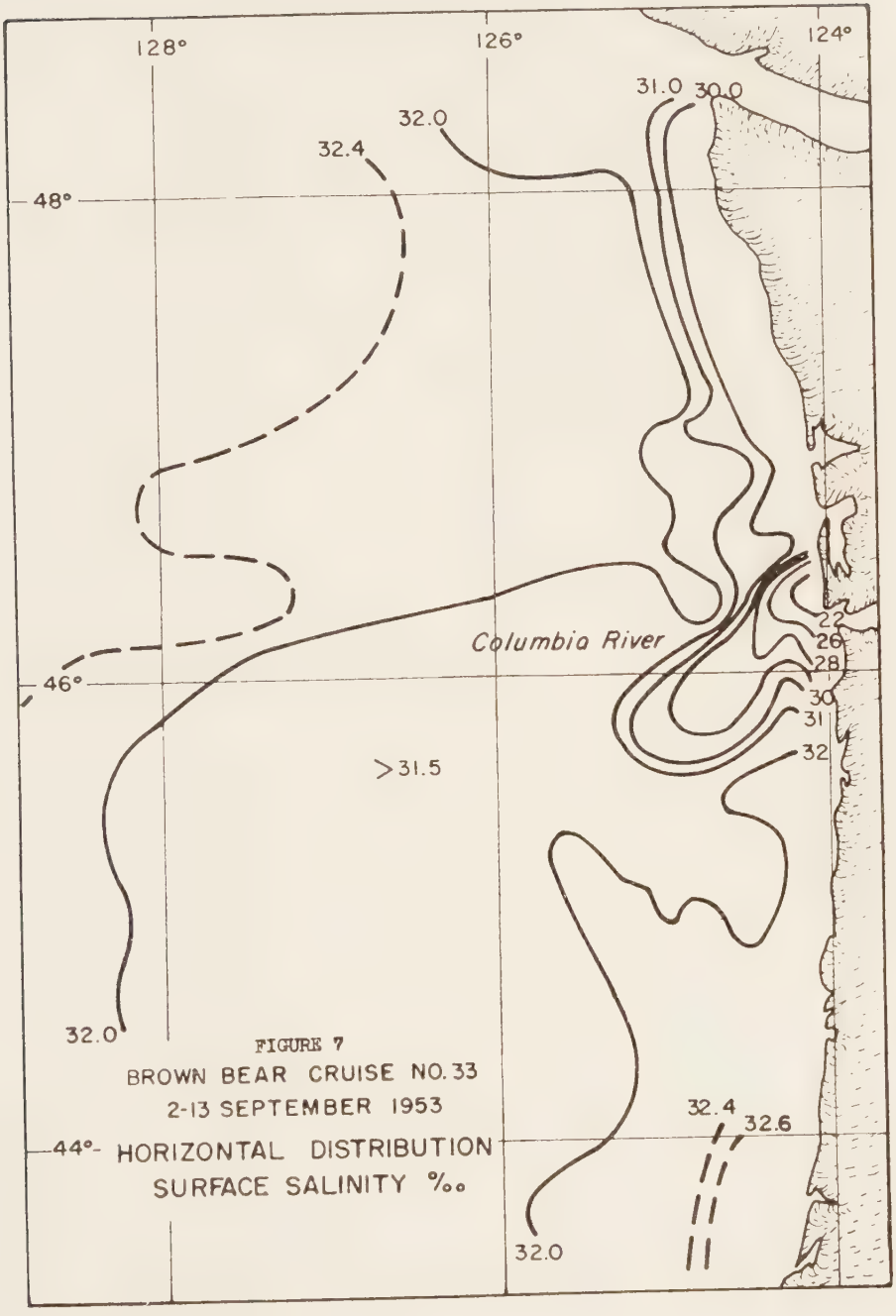


FIGURE 7
BROWN BEAR CRUISE NO. 33
2-13 SEPTEMBER 1953
HORIZONTAL DISTRIBUTION
SURFACE SALINITY ‰

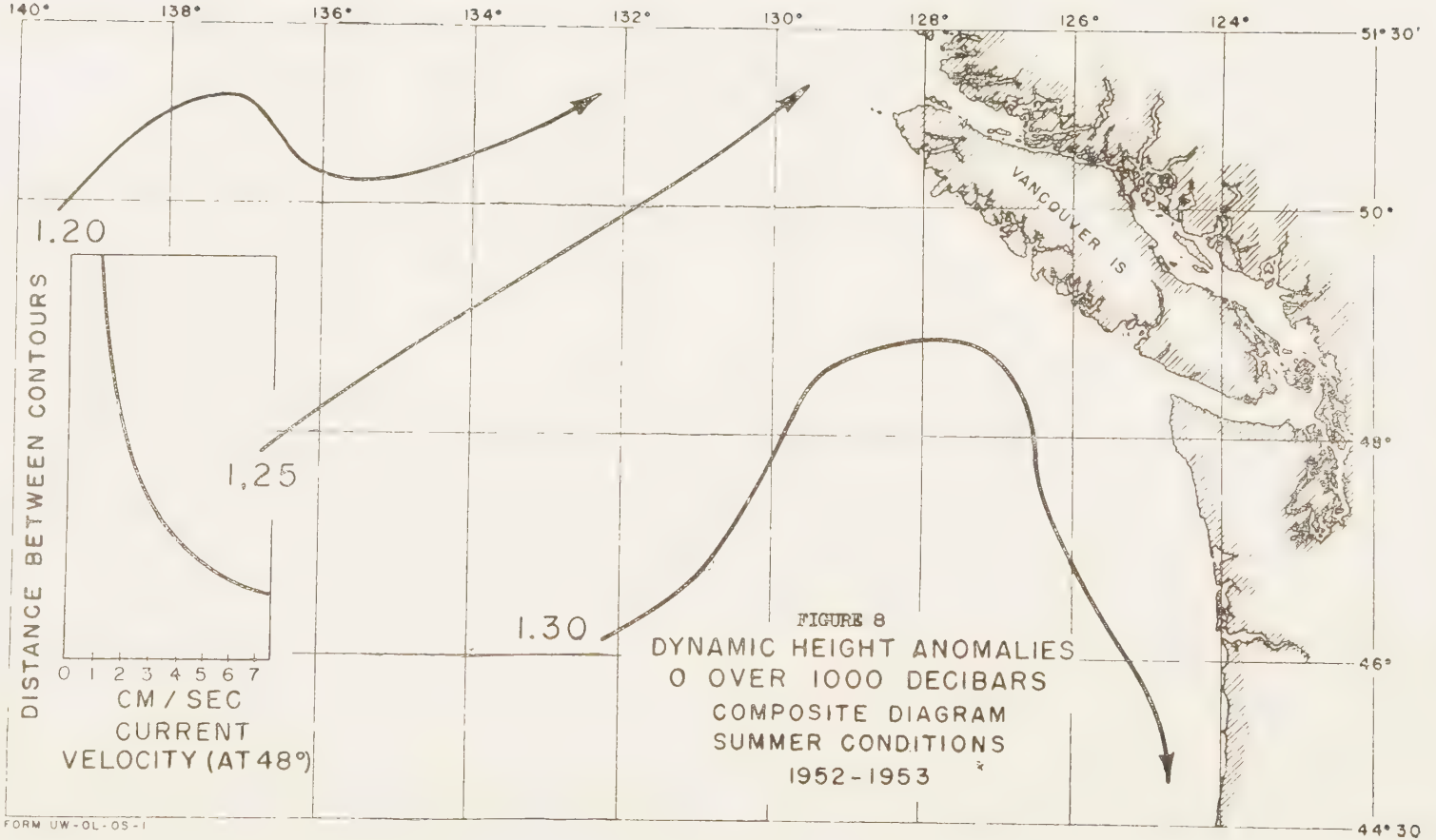


FIGURE 8
DYNAMIC HEIGHT ANOMALIES
O OVER 1000 DECIBARS
COMPOSITE DIAGRAM
SUMMER CONDITIONS
1952-1953

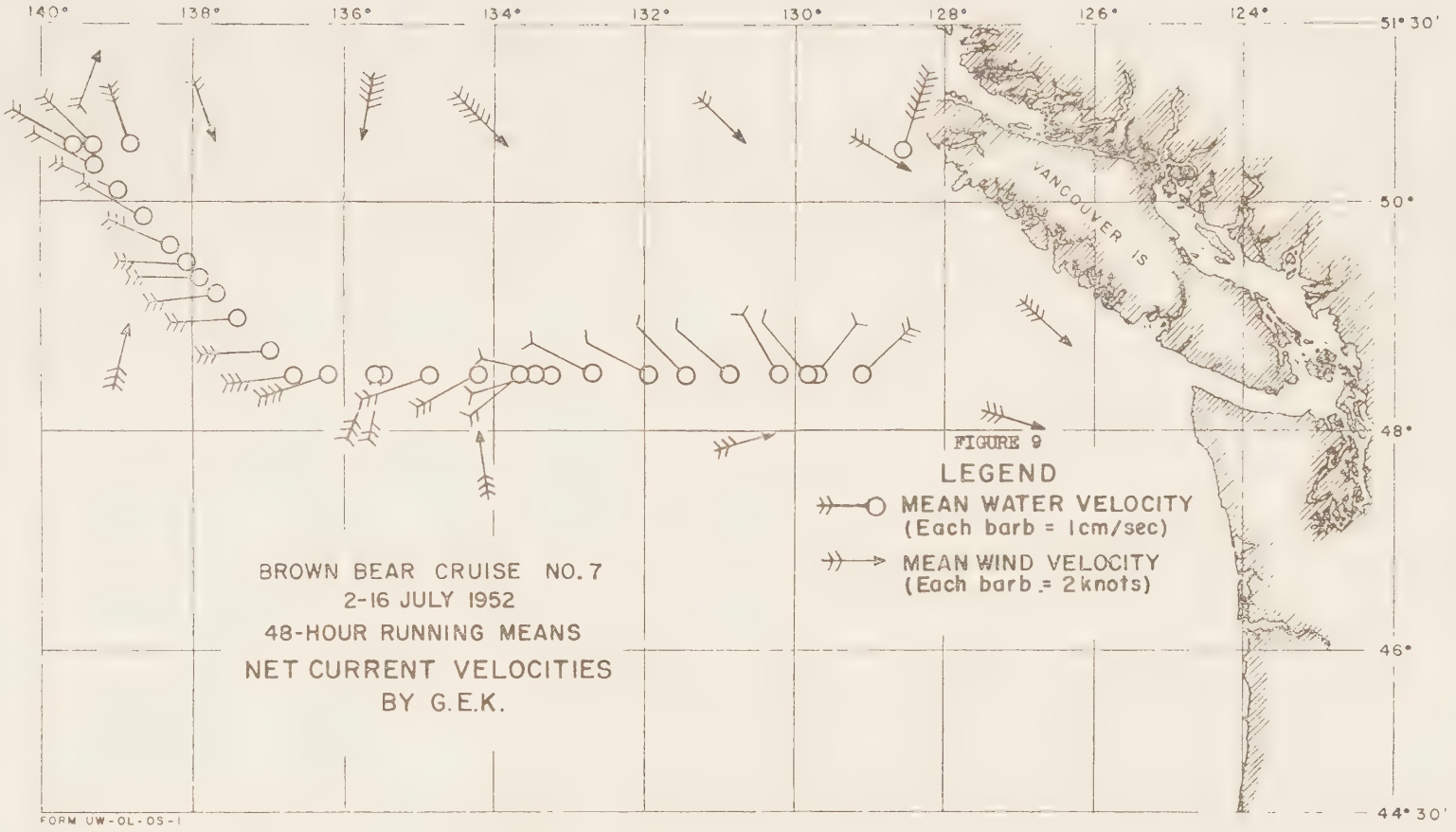

140°
138°
136°
134°
132°
130°
128°
126°
124°
51° 30'
50°
48°
46°
44° 30'
VANCOUVER IS
BROWN BEAR CRUISE NO. 7
2-16 JULY 1952
48-HOUR RUNNING MEANS
NET CURRENT VELOCITIES
BY G.E.K.
LEGEND
MEAN WATER VELOCITY
(Each barb = 1cm/sec)
MEAN WIND VELOCITY
(Each barb = 2knots)
FORM UW-OL-OS-1

FIGURE 9

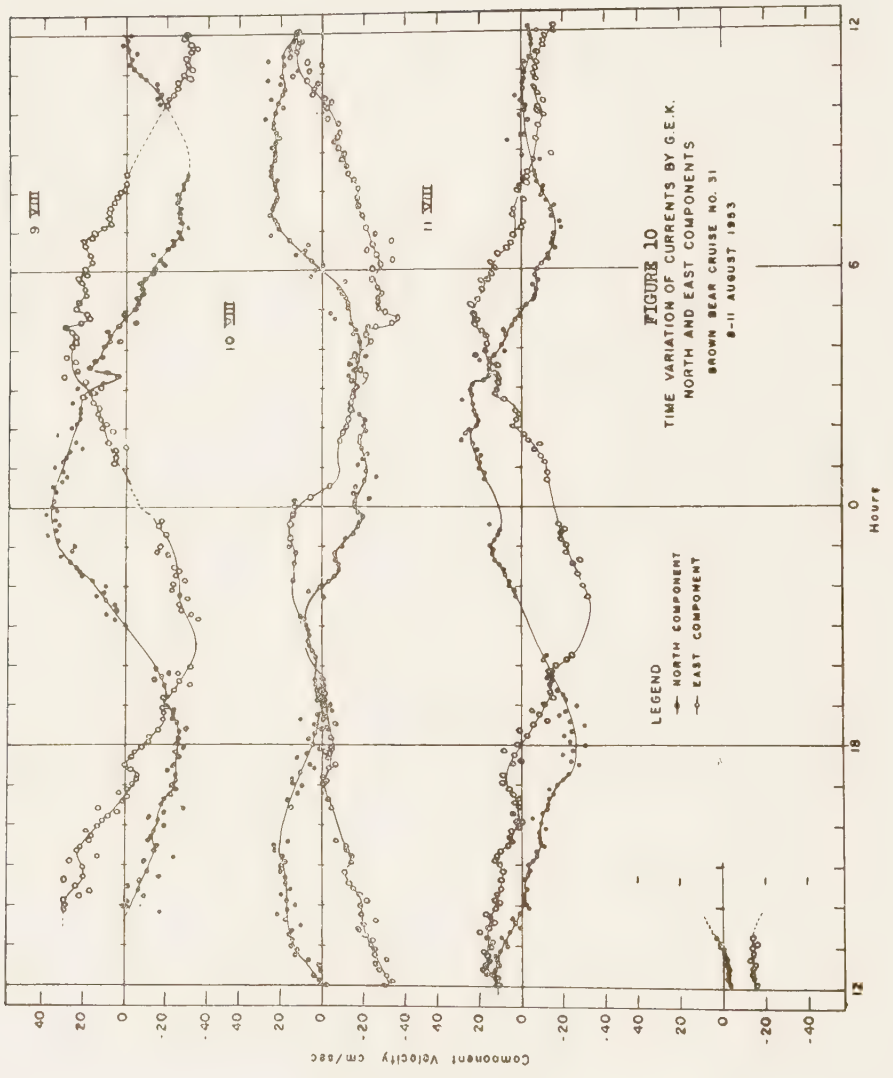


FIGURE 10
TIME VARIATION OF CURRENTS BY G.E.K.
NORTH AND EAST COMPONENTS
BROWN BEAR CRUISE NO. 51
8-11 AUGUST 1953

U. S. NAVY CONTRIBUTIONS TO THE STUDY OF PACIFIC CIRCULATION

By John Lyman
Division of Oceanography
U. S. Navy Hydrographic Office, Washington, D. C., U. S. A.

The U. S. Navy has participated in several different ways in the study of Pacific circulation. The Hydrographic Office, serving as the national repository of information submitted by cooperating observers on merchant vessels of many different nationalities, has for half a century collected the current observations of navigators, obtained by comparison of celestial fixes with dead-reckoning positions. These observations up to the year 1935, reduced to punched cards, have served as the basic materials for the preparation of Hydrographic Office Publications Nos. 568, 569, and 570. Figure 1 is a sample of the data presented in H. O. Pubs. No. 569 and 570, which give not only vector resultant currents for each month for each 1° quadrangle but also the frequency distribution of set and predominant drift for somewhat larger subdivisions.

Observations from 1935 to 1945 have been tabulated and are on file at the Hydrographic Office, while records since 1945 are awaiting punching.

Cooperating mariners in the Pacific also participate in current studies by throwing over bottle papers (Fig. 2). Captain E. R. Johanson of the Matson Navigation Company of San Francisco has taken an especial interest in this subject in recent years, and his name appears frequently in the lists of recoveries, which have been regularly reported in the weekly *Hydrographic Bulletin*. These bottle drifts, while of course they yield no direct evidence as to the precise route travelled by a drifting object between the points of release and recovery, nevertheless are valuable in giving general circulation patterns and minimum values of the set of surface currents. They are particularly useful in forecasting drifts of wreckage and floating mines.

A study of local circulation at Guam in 1949 made by naval authorities for planning sewer outfall locations by releasing a number of drift bottles, yielded unexpected results when several bottles turned up at Talaud and others in the Philippines and Japan (*Hydro. Bulletin* of 7 April 1951).

During the 1930's the U. S. Navy occupied oceanographic stations over a wide range of the eastern North Pacific, in connection with its hydrographic surveying program. Although the immediate objective was to obtain temperature and salinity values that could be used in computing the speed of sound to correct sonic soundings, the data also yield information on the dynamic topography. Observers from Scripps Institution of Oceanography and from the Oceanographic Laboratories of the University of Washington participated in most of this work, and the data were worked up at those respective institutions. Table I lists the vessels engaged in this work.

Part of the HANNIBAL, GANNET, OGLALA, and BUSHNELL data have been published (H. O. Pub. No. 212; Barnes and Thompson, 1938; Goodman and Thompson, 1940; Sverdrup and Staff, 1943).

During World War II the oceanographic investigations of the U. S. Navy in the Pacific were more concerned with studies of underwater sound than with circulation. The atomic bomb tests at Bikini in 1946, however, imposed requirements for the prediction and tracing of the movements of radioactive water. Included in the broad oceanographic and geophysical program of Operation CROSSROADS under the direction of Cdr. R. R. Revelle, USNR, therefore, were several series of oceanographic stations taken by a group of oceanographers under Cdr. C. A. Barnes, USCGR, in the USS BOWDITCH and BLISH, and by another group directed by Mr. D. F. Bumpus and LCdr. John Lyman, USNR, in several units of Destroyer Squadron 7. These results have been discussed by Barnes, Bumpus, and Lyman (1948), and in more detail by Han-Lee Mao and Kozo Yoshida in a forthcoming U. S. Geological Survey professional paper.

During 1946, also, three administrative actions within the U. S. Navy produced results of significance to the study of Pacific circulation. One was the establishment in the Hydrographic Office of a Division of Oceanography, headed first by Dr. R. H. Fleming, Director, and Dr. C. A. Barnes, Deputy Director. These positions are now occupied by John Lyman and Dr. C. C. Bates, respectively. Another was the creation of the Office of Naval Research, including an Earth Sciences Division, headed first by Cdr. R. R. Revelle, and later by Dr. J. N. Adkins. Through contracts administered by the Office of Naval Research, considerable financial support has been given to oceanographic survey programs in the Pacific. The SPENCER F. BAIRD, a former Army tug, converted in 1947 to an oceanographic research vessel for use in the Philippines Fisheries program and transferred to the U. S. Navy in 1952, is operated by Scripps Institution of Oceanography, with funds provided by the Bureau of Ships and the Office of Naval Research. The Navy has also helped support operations of the Scripps vessel

HORIZON in such expeditions as Mid-Pac (1950), Northern Holiday (1951), Shellback (1952), and Capricorn (1952–53), and of the University of Washington research vessel BROWN BEAR.

The third action to be mentioned was the establishment of an oceanographic unit under Mr. E. C. LaFond at the U. S. Navy Electronics Laboratory (LaFond, 1949). In addition to studies of the Pacific with the immediate objective of defining the sound channels or Sofar, LaFond's group has participated in surveys in the Antarctic (Dietz, 1948) and in the Bering Sea (LaFond, *et al.*, 1948, 1952), cooperating in the latter area with Canadian authorities (Lesser and Buffington, 1950). Sofar cruises have been performed by the USS FIEBERLING (Holtsmark, 1949) and SERRANO (Anderson, 1950); and the EPCE(R) 854 has also carried out similar work.

In addition to the data contained in the publications already cited, most of the observations made by the vessels mentioned have been punched onto cards (Fig. 3) as described by Lyman (1953). H. O. Pub. No. 242 lists the cruises which have been so punched, and H. O. Pub. No. 238 is a comprehensive bibliography of the physical oceanography of the Western Pacific.

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U.S. Hydrographic Office, Pub. No. 569, Atlas of surface currents, Northwestern Pacific Ocean, Washington, D.C., 1950.

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TABLE I

OCEANOGRAPHIC SURVEYS OF THE U. S. NAVY HYDROGRAPHIC OFFICE, 1933-1939

VESSEL	YEARS	AREA	NO. OF STATIONS	OBSERVER	REFFRENCE
HANNIBAL	1933	Gulf of Panama	136	R. H. Fleming	Gherardi, 1934
HANNIBAL	1934	Central America	12	. . . . .	Gherardi, 1935
HANNIBAL	1935	Central America	36	. . . . .	Leahy, 1936
GANNET	1933	Aleutians	42	C. A. Barnes	Gherardi, 1934
BUSHNELL	1934	Aleutians to Hawaii	18	R. R. Revelle	Gherardi, 1935
OGLALA	1935	Aleutians	12	. . . . .	Leahy, 1936
		Aleutians to Cape Flattery	12	J. R. Galbraith and R. L. Hulbert	"
		Cape Flattery to Hawaii	14		"
LOUISVILLE	1936	Los Angeles to Hawaii	10	E. G. Moberg and R. Doescher	Kays, 1937
MILWAUKEE	1936	Hawaii to San Francisco	1		"
BUSHNELL	1939	Panama to Lower California	9	E. C. LaFond	Bryan, 1940
BUSHNELL	1939	San Diego to Honolulu	9		"

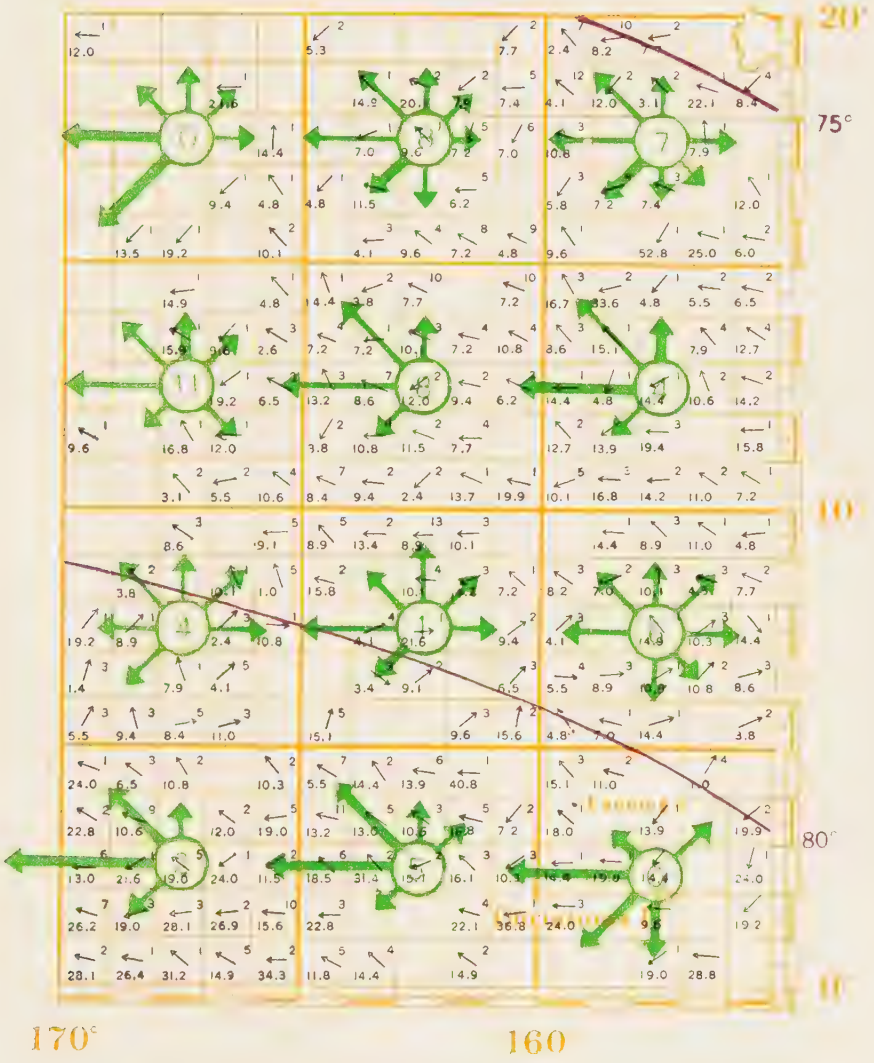


FIGURE 1

PRNC-NHO 84

BOTTLE PAPER

U.S. NAVY
HYDROGRAPHIC OFFICE
WASHINGTON 25, D. C.
U. S. A.

(PLEASE USE LEAD PENCIL)

Thrown overboard by (Give name of master and observer):

Master, . .

Officer,

Vessel,

Date, . .

Latitude, .

Longitude, . .

INSTRUCTIONS TO FINDER

Trouvé par (indiquer le nom, date et lieu).
Gefunden von (man gebe Namen, Datum und Ort an).
Gevonden door (men geve naam, dagteekening en plaats op).
Trovato da (dare il nome, data e luogo).
Hallado por (dar el nombre, fecha y paraje).
Achado por (dar o nome, date e paragem).
Trovita de (ckribu nomon, daton, k, lokon).

Finder,

Date, ...

Locality,

Post-office address of finder,

The finder of this will please send it to any United States Consul, or forward it direct to the U.S. Navy Hydrographic Office, Washington 25, D.C.

La personne qui trouvera ce papier est priée de l'envoyer à un consul quelconque des Etats-Unis, ou de le faire parvenir directement à la section d'hydrographie du ministere de la marine à Washington 25, D.C.

Der Finder Dieses wird ersucht es irgend einem Konsul der Vereinigten Staaten zuzusenden, oder es dem hydrographischen Amte des Marineministeriums in Washington 25, D. C., direkt zugehen zu lassen.

De vinder van dit papier wordt verzocht, het tot een Consul dér Vereenigde Staten, of rechtstreeks naar het Hydrographische Ambt des Departements van Marine te Washington 25, D. C., te zenden.

Chiunque trovi questo è pregato d'inviarlo a qualche Console degli Stati Uniti d'America, o di farlo pervenire direttamente alla Sezione d'Idrografia del Ministero della Marina a Washington 25, D. C.

Se suplica a la persona que hallar esto que lo envíe á algun Cónsul de los Estados Unidos de América, ó que lo remita directamente á la Seccion de Hidrografia del Departamento de Marina en Washington 25, D. C.

Roga-se a pessoa que achar isto o favor de o enviar a um dos Consules dos Estados Unidos da America, ou de o encaminhar directamente á Secção de Hydrographia da Repartição da Marinha em Washington 25, D. C.

Oni petas ka la trovanto sendu la paperon al iu Amerika Konsulo, aŭ ekte al U.S. Navy Hydrographic Office, Washington 25, D. C., U. S. A.

This form should be placed in a strong bottle. The cork should be driven in flush with the rim and covered, preferably with sealing wax.

If the finder of this paper will return it to the U. S. Navy Hydrographic Office, Washington 25, D. C., direct, or through any United States Consul, he will thereby assist in the verification of the circulation of ocean currents. His services will be very much appreciated by all mariners.

There are no funds available for paying rewards to the finders.

FIGURE 2

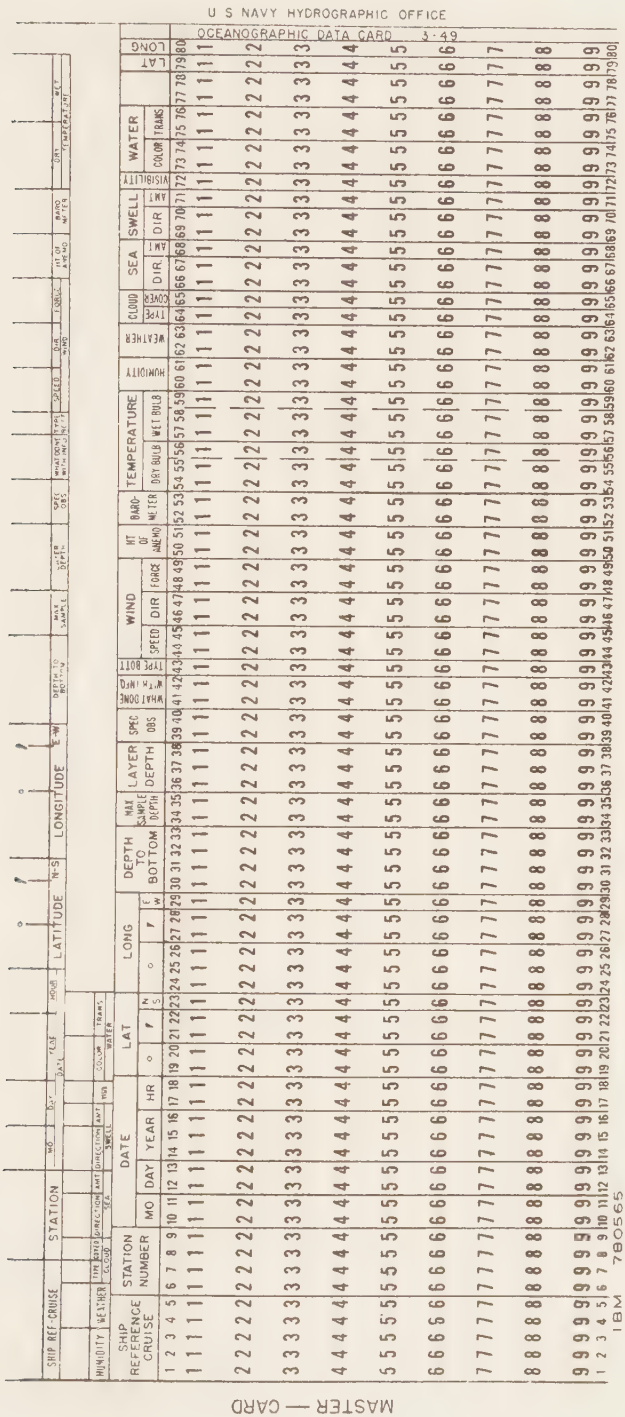
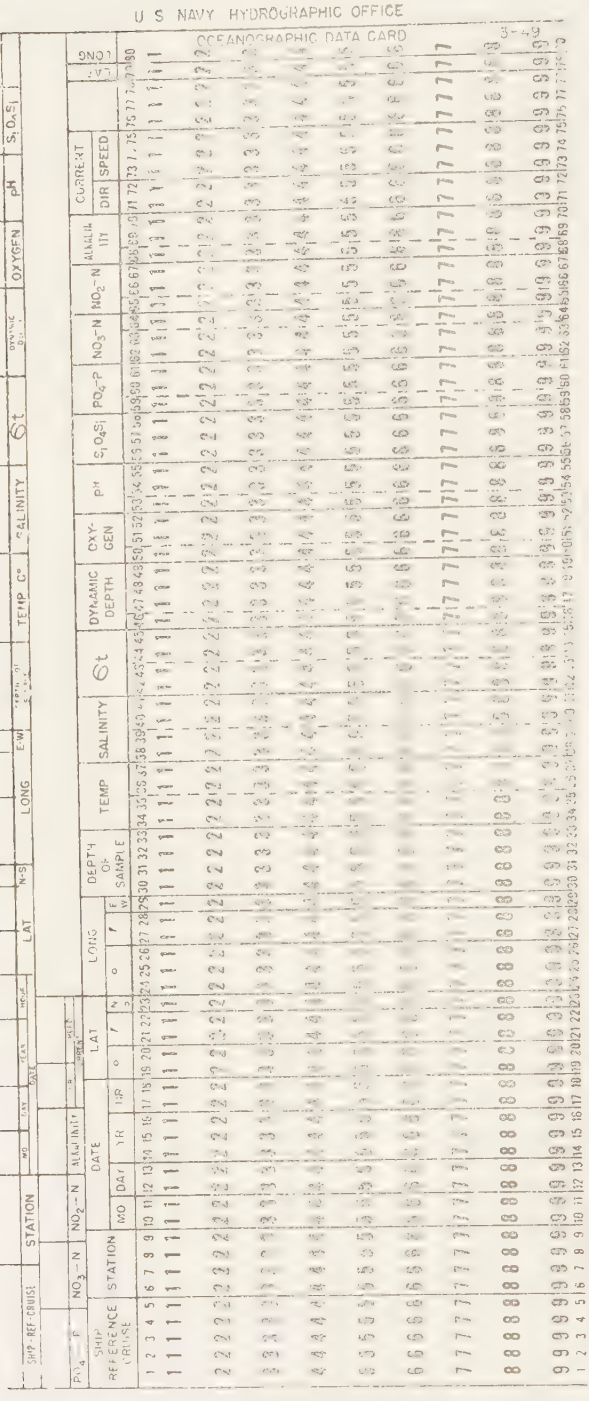

U S NAVY HYDROGRAPHIC OFFICE
OCEANOGRAPHIC DATA CARD 3-49
MASTER — CARD
IBM 780565

FIGURE 3(a)


U S NAVY HYDROGRAPHIC OFFICE
OCEANOGRAPHIC DATA CARD
DETAIL CARD
FIGURE 3 (1)

ON THE VARIATION OF THE KUROSHIO NEAR THE JAPAN ISLANDS

By D. Shoji and K. Suda
Hydrographic Office, Tokyo, Japan

Introduction

There have been many investigations concerning the nature of the Kuroshio, but the study on its variation is yet very rare, and the hourly variations of its pass and strength may be said to be almost unknown. In recent years, as the results of oceanographic observations gradually piled up, it was made clear that the ocean currents which have been thought rather stationary, made a comparatively violent variation. But the observations are very poor compared with other scientific fields, for example, with meteorology. The cause or the mechanism of variation of ocean current can not be cleared at the present time. We intended, therefore, in the following only to describe some example of the observed variation of the Kuroshio.

1) A Cold Water Mass off the South Coast of Honshu

It was first reported by fishermen in 1931 that a large cold water mass of a diameter of about 100 sea miles appeared off the south coast of Honshu and that the Kuroshio flowed around this cold water mass. According to this report the Hydrographic Office, the Meteorological Observatory and the Fisheries Research Institute of Japan made many oceanographic observations in this area (Figs. 1–5). At first this cold water mass (the water temp. at 200 meters was about 10°C in it and the opposite side of Kuroshio about 18°C) was off the Kii Peninsula, and then moved eastward a little and its existence was confirmed until 1944. Owing to the War the observation was interrupted, and when reopened in 1946 the cold water mass was much contradicted, and then disappeared. Hereafter, the cold water mass appeared in winter of 1946–47, 1950–51 and 1952–53 in this area, but it did not so develop, and the appearance of this cold water mass seems to be a seasonal phenomenon in recent years. It is clear from the T–S diagram and other evidences that this cold water mass is a consequence of the upwelling of the cold intermediate water. But why this upwelling happens so extensively and why the Kuroshio runs around this, departing from the Japanese coast, has not been satisfactorily shown. It is true that the

bottom configuration of this area is suitable for an upwelling. Dr. Uda and Dr. Koenuma explained this phenomenon as follows: When the North Pacific High Salinity Water (Kuroshio Water) weakened and the strength of the Subarctic intermediate water (Oyashio Water) increased, this cold water mass appeared. He pointed out that prior to the appearance of the cold water mass in 1934, cold water off the coast of Sanriku prevailed so intensively that the northeastern part of Japan had suffered a very cold summer in 1934–35. It may be explained that the weakening on the Kuroshio in recent years has caused the appearance of a cold water mass in winter.

Before the appearance of the cold water mass in 1934, the famous Muroto typhoon had passed the central part of Japan, and in recent years the cold water mass appeared after a strong typhoon passed near this area. The effect of typhoon may be one of the causes of the upwelling of cold water mass.

Summarizing the above observations, the strengthening and weakening of the Kuroshio and Oyashio is the major cause of the appearance of the cold water mass and the bottom configuration and typhoons have much effect on it.

2) A Violent Variation of Oceanographic Condition off the Boso Peninsula

It is well known by fishermen that ocean currents change their course and other oceanographic conditions vary in a very short time. But the oceanographic observation is seldom carried out in so short an interval that there are few examples for these variations in the record of observations.

In this paragraph we intend to describe an example in which several observations were carried out in a short interval in the same area, and a large variation of oceanographic condition was observed. But in this example, too, the shortest interval of observation was 10 days, and from the variation of observed water temperature, etc., this is not sufficient to make clear the detailed variation which was taking place in the ocean.

Figure 6 shows the sectional distribution of water temperature observed by the Hydrographic Office from March to May, 1944, off the Boso Peninsula. These five observations were carried out on an almost similar line (Fig. 7). As in this area the Kuroshio deflects eastwards departing from the Japan Islands and the Oyashio reaches to the north of the Kuroshio, the oceanographic condition in this area is very variable.

Between 3 and 25 March, the water temperature lowered to about 3–4°C in the whole region, and on 11 April there appeared a minimum

of very low temperature (and very low salinity) of 3–4°C at 200-meter layer near the coast. (This temperature minimum is a very rare phenomenon as this appeared so far south.) These results indicate that the Oyashio came down farther south than usual. On 22 April, 11 days after the former observation, the temperature minimum disappeared completely and the isotherms inclined so sharp that this indicated that there was a strong northeasterly current, that is the Kuroshio was flowing in this area. From the observation of 9 May, the temperature rose generally and warm water occupied this area.

The variation of the sea water has close connection with the meteorological conditions. So we examined the wind observed at the Chosi Weather Station. From 13 March to 11 April northern winds prevailed. On 18 and 28 March and 8 April the wind velocity exceeded 20 m/s (wind direction N or NNE) and on 18 March and 8 April winds of more than 10 m/s continued more than 24 hours. After 11 April it was generally calm and the wind direction was variable. From these data it may be concluded that the southward flow of cold water from March to April was caused by the strong north wind of the same period.

3) The Translation of the Kuroshio and its Periodic Character as Observed by the Mean Sea Level

Due to La Fond the variation of water level observed at tidal stations (the effect of tide eliminated by taking suitable mean values) is almost the same as the variation of dynamic height of the neighbouring sea surface.

The difference in the dynamic height on both sides of an ocean current like the Kuroshio reaches as much as about 100 cm. Therefore if water level is observed at an island situated in the stream of the Kuroshio, we can know the translation of the Kuroshio continuously. For this purpose we put a tidal station at Hachijo-sima, and observed the variation of water level, and at the same time the record of three tidal stations on the coast of Honshu were also examined. As the variation of the current was very sharp in some cases, we used daily mean sea level (25-hour mean); and to eliminate the barometric effect, correction was performed assuming 1 mmb. of air pressure corresponds to 1 cm. of water level. Air pressure was taken from the record of the nearest weather stations.

At first it is necessary to examine whether the mean sea level varies parallel with the dynamic depth or not. Figure 8 shows the correlation between the dynamic depth obtained from oceanographic observations and the sea level. As both values have error of a few centimeters, we can conclude that proportionality exists fairly well between these values.

The observation of mean sea level at Hachijo-sima has been continued since May 1951. Figure 9 shows the results from September 1951 to September 1952, with the values of Kushimoto, Ito and Mera Tidal Stations (Central Meteorological Observatory). The position of the tidal stations is shown in Figure 10.

(i) The range of variation of mean sea level at Hachijo-sima was very large compared with other tidal station. While the differences between maximum and minimum were about 50 cm. at other stations, the difference at Hachijo-sima reached to 140 cm. This was caused by the translation of the Kuroshio. To demonstrate this we shall compare the variation of sea level with the oceanographic observations carried out in the same period. The water level at Hachijo-sima was between 250 cm. and 260 cm. until September 1951. Then it lowered greatly from the middle of October and from November 1951 to April 1952 (December 1951–February 1952 observation lacked) it remained between 170 and 220 cm. At the beginning of May, it rose suddenly about 50 cm. and then continued to rise slowly until September 1952. According to the oceanographic observations, in May–August 1951, the Kuroshio was obviously to the north of Hachijo-sima, in September–December, as there was no observation, the condition was not clear, but from the Ten-day Marine Report of the Central Meteorological Observatory, there appeared a cold water mass in this area. In February 1952 a cold water mass was situated in Enshu-nada and the Kuroshio run around this and Hachijo-sima was situated at the north boundary of the Kuroshio (Fig. 5). In April the Kuroshio was flowing near Miyake-sima. These facts were well coincided with the variation of sea level, and we can conclude that by the observation of sea level, it is possible to pursue the translation of the Kuroshio.

The slope of sea surface at the strong current of the Kuroshio can be assumed to be about 10–15 cm/10 miles. Therefore, that the sharp rise of the sea level at the beginning of May was a rate of about 10 cm/day, indicated that the velocity of translation of the Kuroshio was 5–10 miles/day, namely 0.2–0.4 knots.

This cold water mass was much smaller in scale and continued in shorter time than the one mentioned in the preceding paragraph. It is interesting to note that before the appearance of this cold water mass a strong typhoon, Ruth, had swept over our country on 15 October.

(ii) It was made clear that the variation of mean sea level at Hachijo-sima had close connection with the translation of the Kuroshio. The most interesting point in the variation is that there appear some remarkable periodic changes and this may indicate that there are corresponding meanderings of the Kuroshio.

The most distinguished one was seen from March to April, 1952. The period was 20–30 days and the wave height was 30–50 cm. As the number of waves is only a few, it can not be decided whether this is a durable phenomenon or not. But it is clear that this is due to the translation of the Kuroshio from the large range of variations.

From May to September 1952, there appeared a periodic change of sea level of much smaller amplitude than the former one. Figure 12 shows the 5-day moving average of mean sea level. The mean of wave height was 5 cm. over a period of 14 days. As the amplitude of this wave is rather small, it is not possible to conclude that this is due to the oscillation of the Kuroshio. But it may not be the wave of astronomical origin, for if it is one of the astronomical tide, it must appear in every time and place. Whether this wave is progressive or not, and also its wave length and velocity, can not be decided on account of lack of materials.

(iii) In September 1951 and 1952 the Kuroshio was to the north of Hachijo-sima in both cases. But the monthly mean level was higher about 34 cm. in 1952 than in 1951, and the difference between Hachijo-sima and Ito was 27 cm. in two cases. The difference of sea levels on both sides of the Kuroshio is proportional to the mean velocity of the Kuroshio. Therefore, this means that the Kuroshio was stronger in September 1952 than in 1951. In fact, from the observation, the Kuroshio was very strong in the summer of 1952 as compared with usual years. Hachijo-sima is not the most suitable position to know the strength of the Kuroshio, for it often comes out of the stream.

It may be very important for oceanography to know the annual and secular variation of the Kuroshio by observation of sea level at some adequate places.

Conclusion

We have described some example of variation of the Kuroshio, but the variation of the Kuroshio can not be cleared up without the cooperation of the scientists of all nations around the Pacific, for the Kuroshio is only a fraction of the great circulation of the Pacific Ocean.

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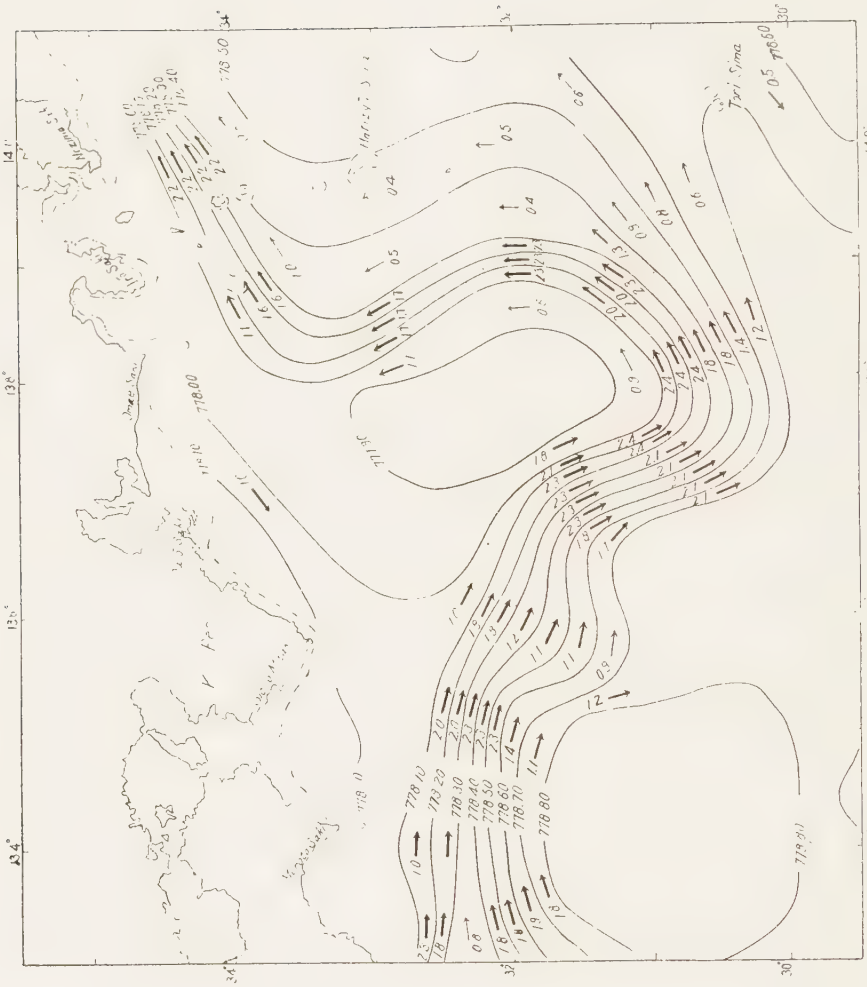


FIG. 1.—Dynamic Topography of Surface Relative to 800 db. (August 1938)

FIG. 2.—Horizontal Distribution of Temperature at 200 m Layer.
(August 1938)

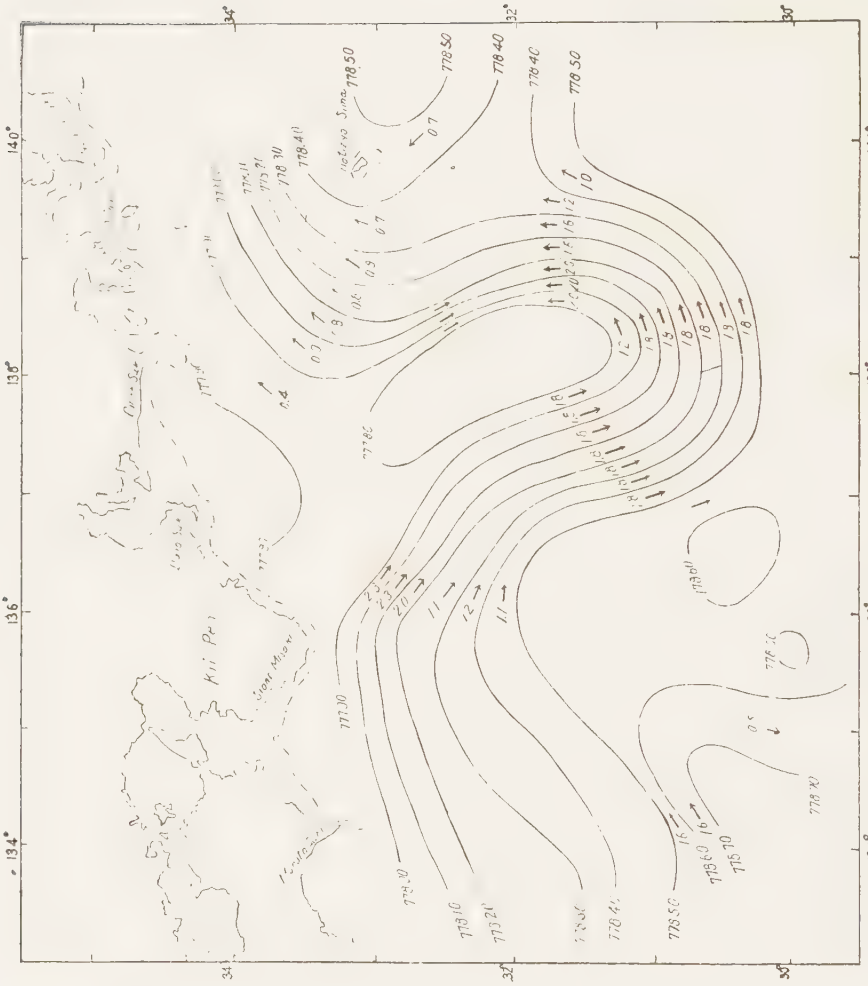


FIG. 3.—Dynamic Topography of Surface Relative to 800 db. (April 1943)

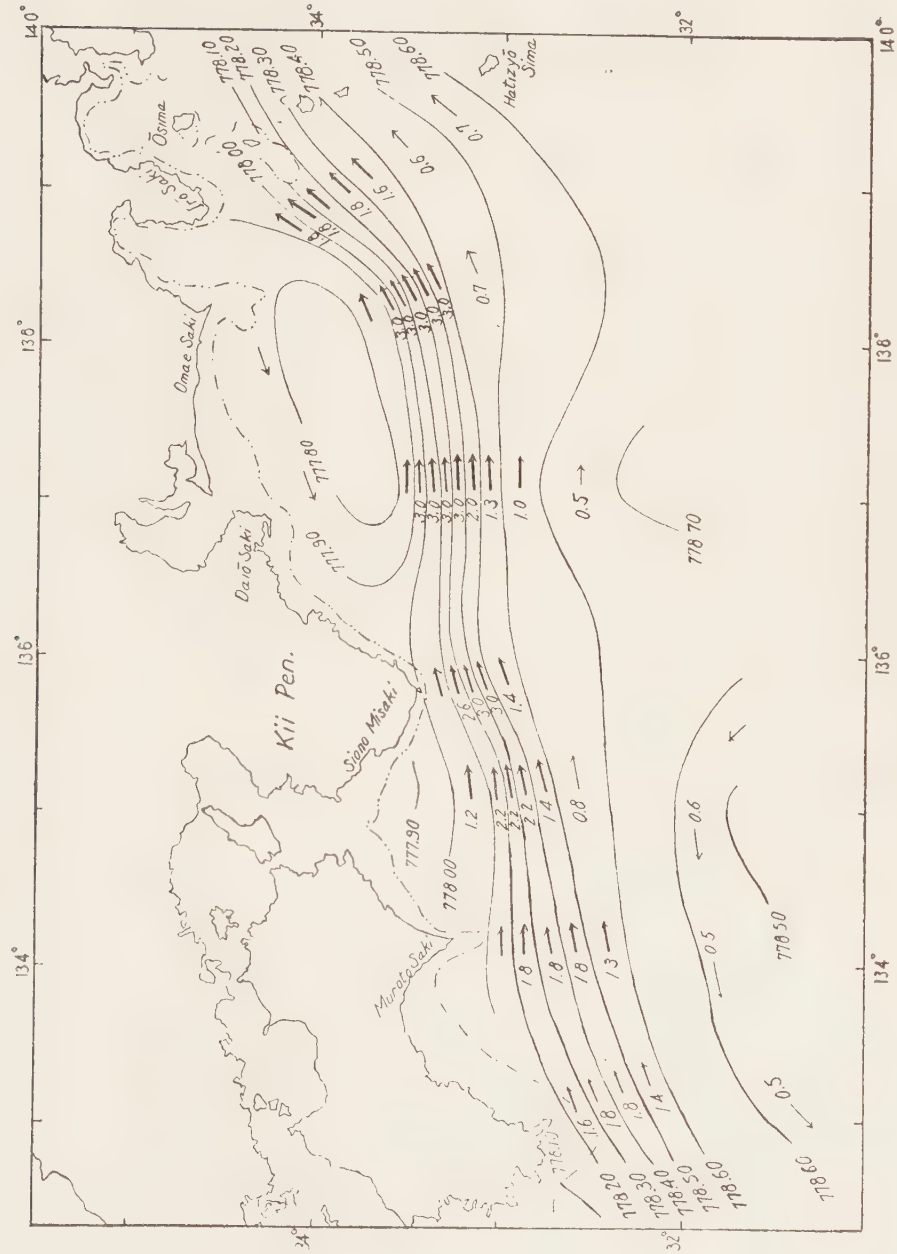


FIG. 4.—Dynamic Topography of Surface Relative to 800 db. (May 1951)

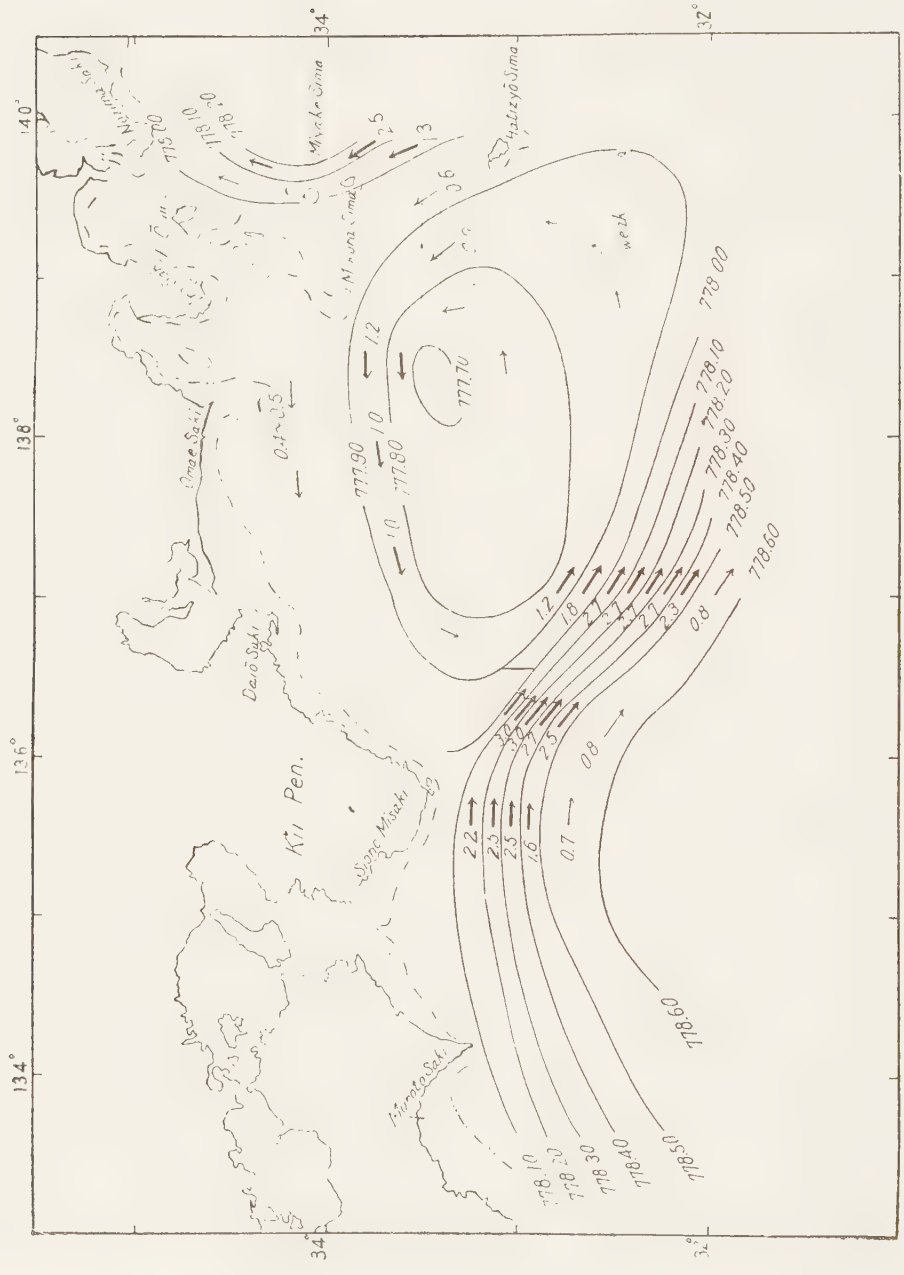


FIG. 5.—Dynamic Topography of Surface Relative to 800 db. (February 1952)

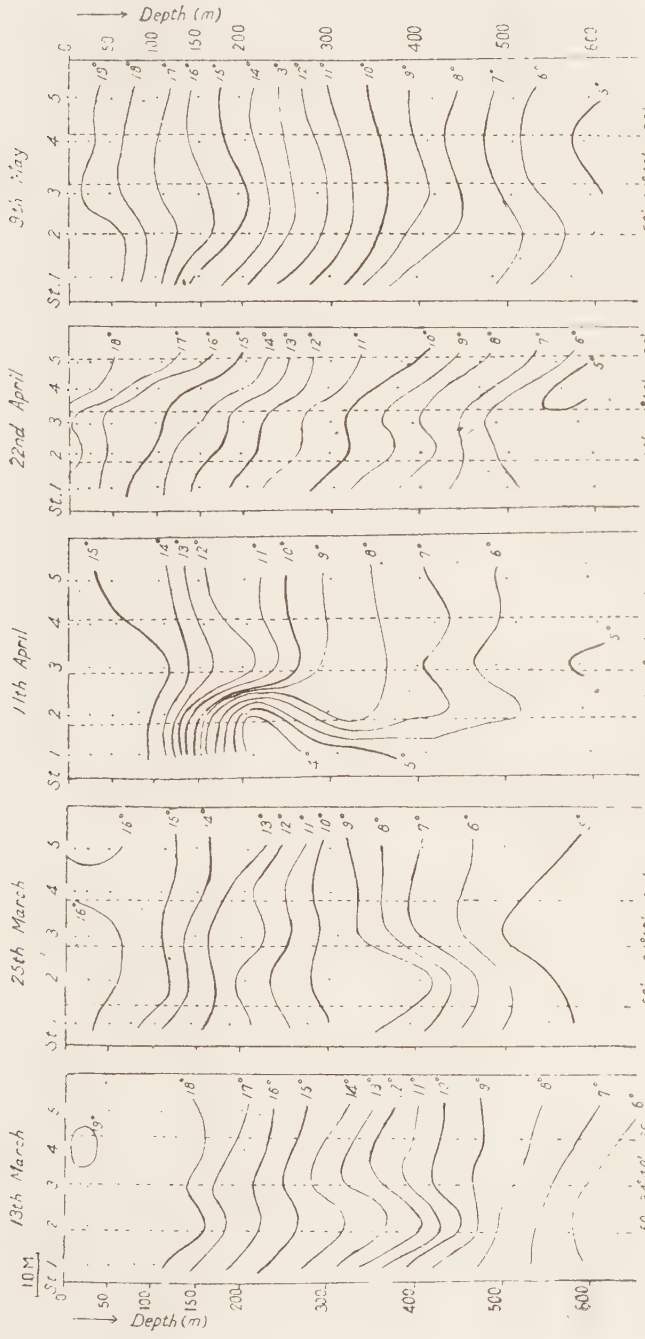


FIG. 6.—Sectional Distributions of Water Temperature. (March-May, 1944)

FIG. 7.— Observation Stations. (March-May, 1944)

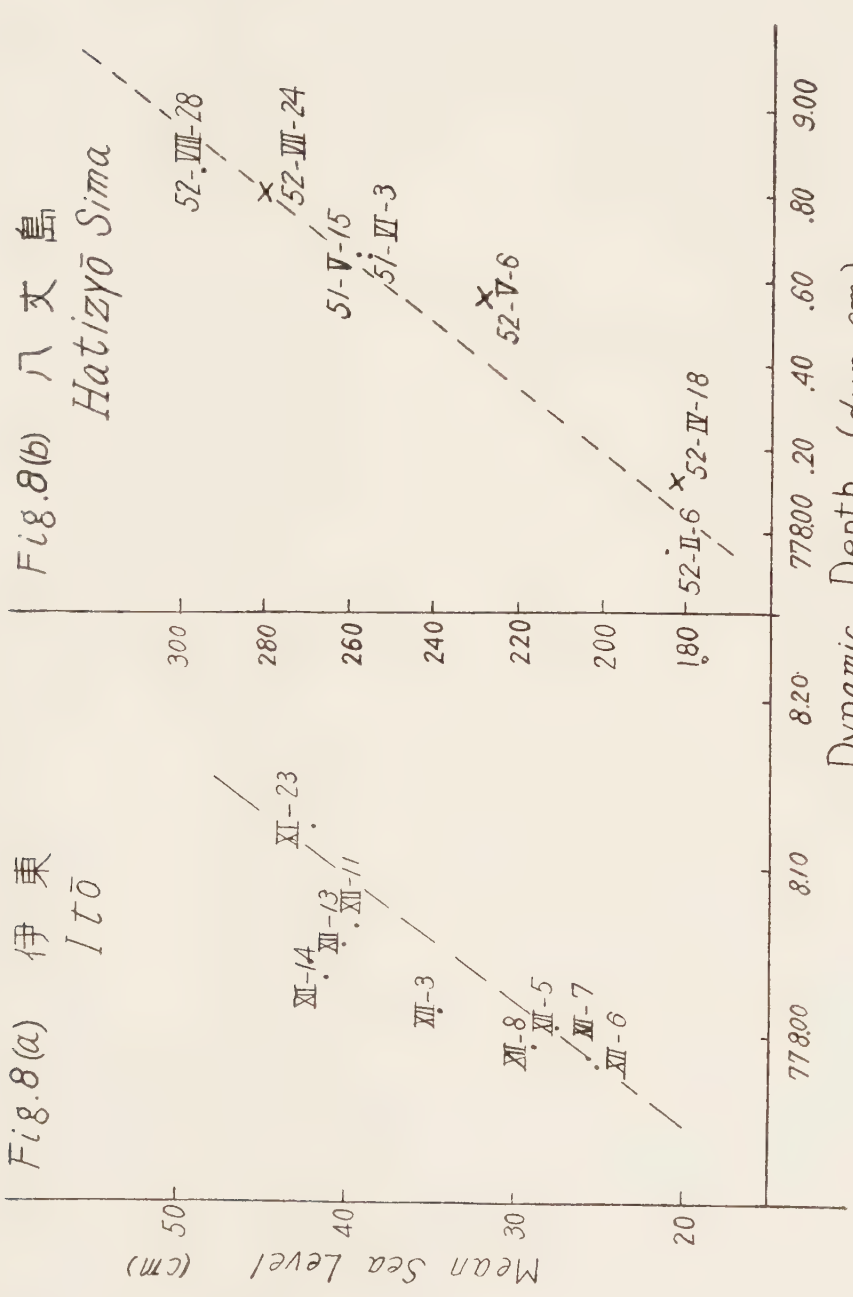
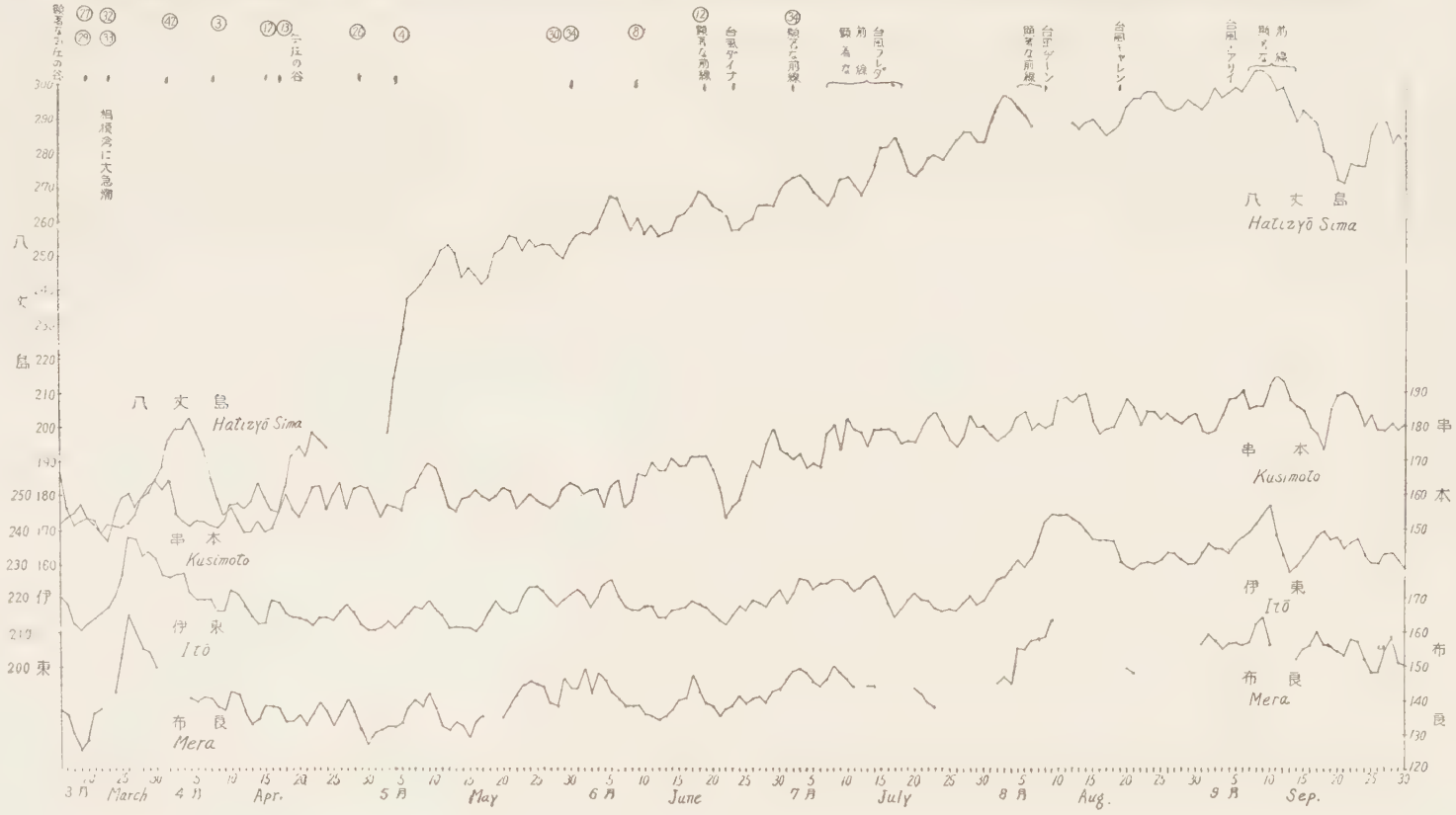


FIG. 8.—Correlation between Mean Sea Level and Dynamic Depth at Hachijo-sima.

第 9 図 (a) 八丈島 三宅島 串木 伊東 布良における日竹林位の変化 Fig. 9 Variation of Mean sea level at Hachijyō Sima, Miyake Sima, Kushimoto, Ito, Mera

第 9 図(b) 八丈島 三宅島 串本 伊東 布良における日平均水位の変化　Fig. 9 Variations of Mean Sea Levels at Hatizyō Sima, Miyake Sima, Kusimoto, Itō, Mera.



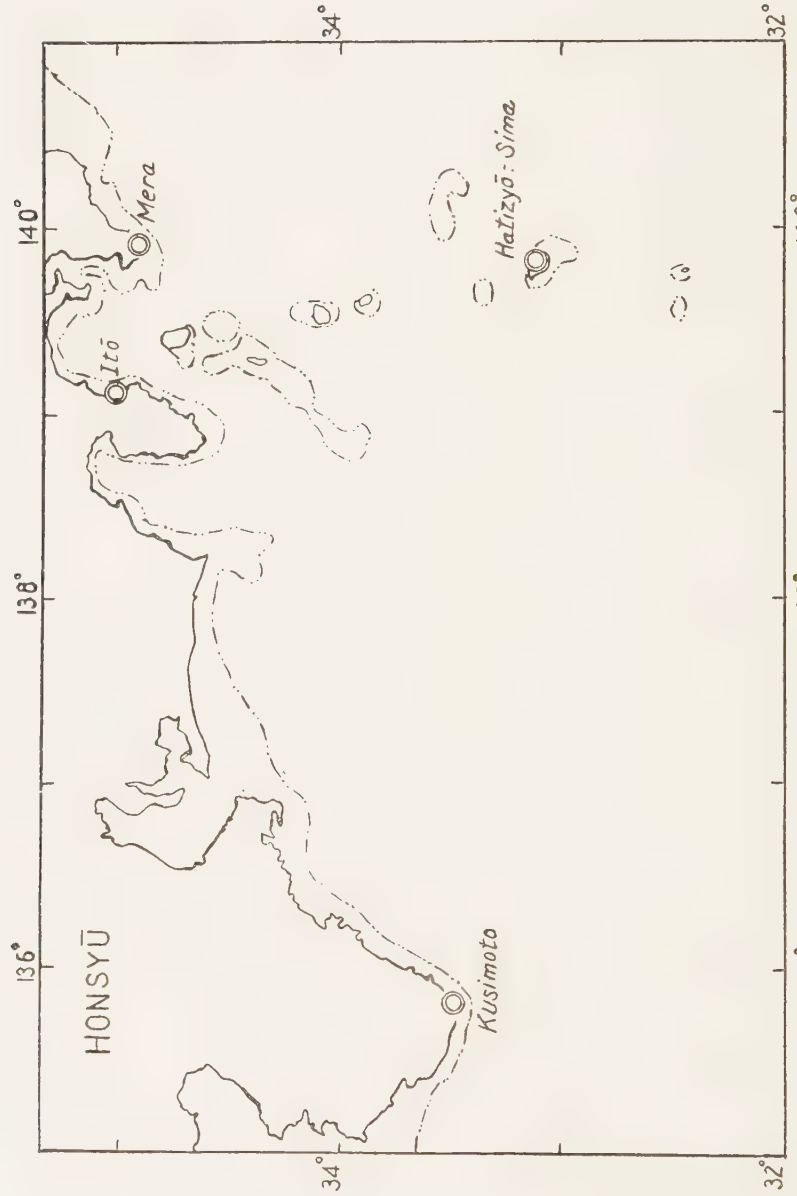


FIG. 10.—Positions of Tidal Stations.

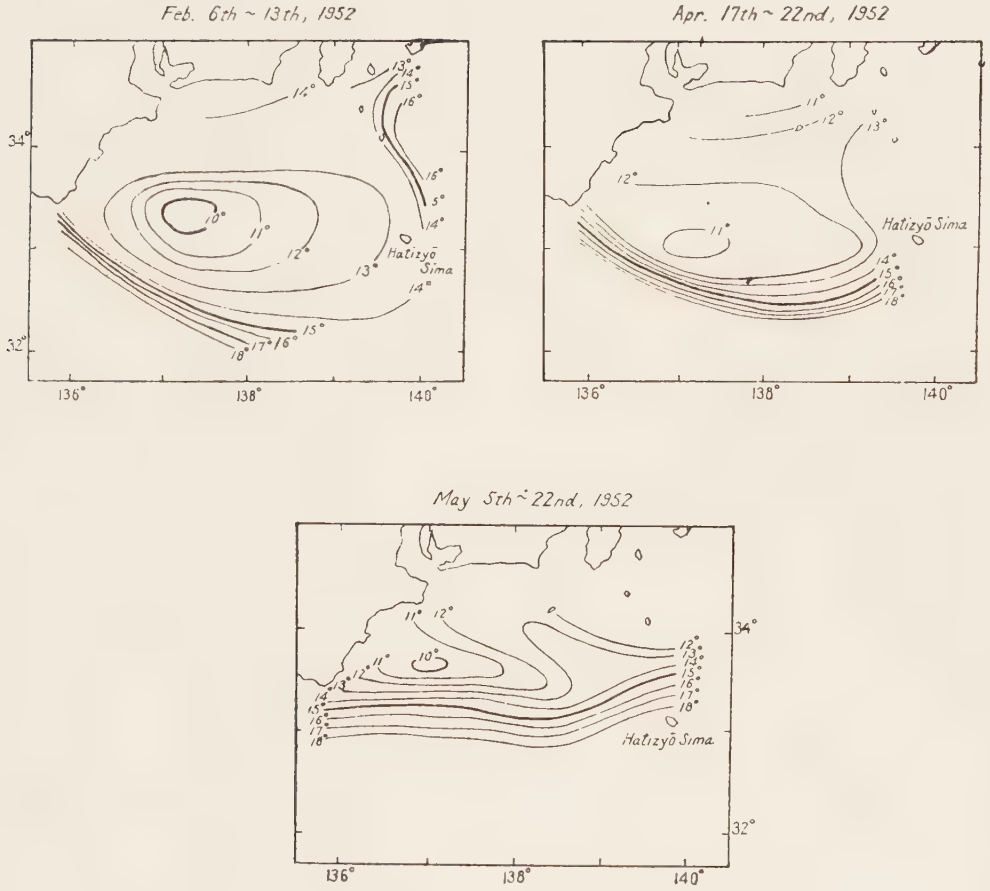


FIG. 11.—Horizontal Distribution of Water Temperature at 200 m Layer. (Feb.–May, 1952)

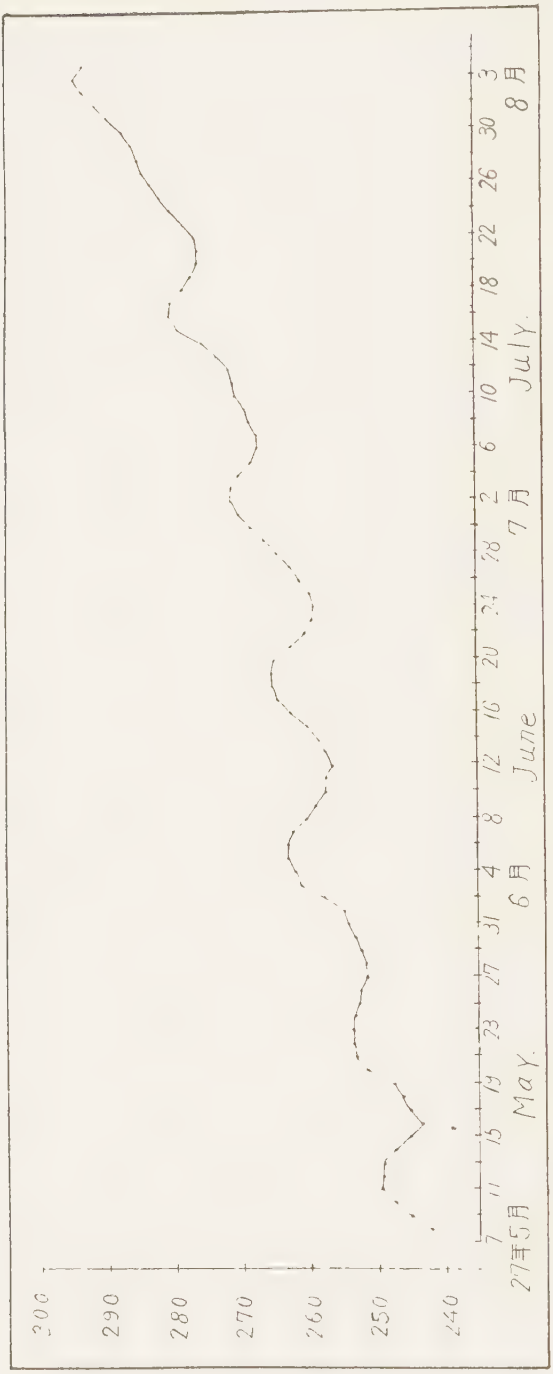


FIG. 12.—Periodic Variation of Daily Mean Sea Level at Hachijo-sima.

SEDIMENTATION IN THE DEEP SEA

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A new era in submarine geology was opened through the development of the new technique first used from the Swedish Deep-Sea Expedition with the "Albatross" in 1947–48. Cores of unprecedented length approaching 20 metres were raised from great depths by means of the Nullenberg piston-core sampler. The thickness of the sediment layers in the open oceans was for the first time measured by means of Weibull's seismic reflexion method. The water-layers immediately above the deep-sea bottom were sampled by F. Koczy and their content of suspended particles studied by Jerlov, whereas detailed achograms of the bottom configuration down to depths of about 7000 metres were registered by a new kind of echograph, revealing the microstructure of the ocean floor. Finally, the first values were obtained of the geothermal gradient in the deep-sea deposits by means of a geothermometer plunged into the bottom to a depth of over 10 metres. My short summary to be given here of the new aspects obtained through this and through following expeditions (Danish, British and American) will be limited to *sedimentation in the deep sea,* as revealed mainly through the study of the long "Albatross" cores, especially through work by Gustaf Arrhenius, geologist to our expedition, for a number of E. Pacific cores.

The 200 and odd "Albatross" cores were taken along a course of over 40,000 nautical miles in all three oceans. Mainly for technical reasons, the course was laid near the Equator. Our studies have principally been directed towards stratification, rate of sedimentation, total thickness, radioactivity and, to a certain extent also, diagenetic alterations, sources and transportation.

Our long cores revealed that stratification of the sediments, earlier considered as rather exceptional, is on the contrary very common, especially near the equator, where the equatorial current system gives rise to zones of divergence with upwelling deep water, rich in nutrient salts and consequently also in plankton-vegetation and -population. Highly spectacular cases of abrupt changes in the composition of the sediment, especially transitions from Red Clay to Calcareous Ooze and *vice versa,* were often found. From his study of the S. Pacific cores Arrhenius has been able to draw conclusions regarding the paleocli-

matic conditions and the stability of the surface current system during the Quaternary Age. On the other hand, cores of apparently homogenous Red Clay, up to 15 meters long, have been raised both from the Atlantic and especially from the Pacific depths, the lowest strata of which were formed during late Tertiary Time. This first evidence of *Red Clay of Tertiary age* has forced us to a revision of our earlier views on the formation of this sediment, largely based on the hypothesis of the lime-dissolving power of the ice-cold Antarctic bottom current. This explanation cannot well hold for the formation of Red Clay in the Tertiary age. I suggest that the lime-dissolving power of magmatic volatiles from the substratum affords a more general explanation. As regards the rate of sedimentation there are at present three ways of obtaining at least approximate values. One is through biological analyses of the foram tests which, through the work of Schott in Hannover, Phleger and his co-workers at Scripps Institute, Ovey and Wiseman in London a.o., have yielded unmistakable proofs of past climatic changes, which have been brought into relationship with paleoclimatic variations, especially the cold ice stages and the warm interglacial stages during Quaternary Time. A clear-cut time relationship has so far not been established, but recent work by Wiseman in London seems to open promising prospects to this direction. Another method, especially by Arrhenius, is based on the assumption of a constant rate of accumulation of *titanium* from the "lutite veil" settling on the ocean floor. Recent work by Correns a. o. have, however, raised doubts on the general applicability of titanium-age determinations.

A third method which we have developed and pursued in Göteborg in collaboration with specialists in Vienna and in Brussels, makes use of radioactive age-determinations. The surprisingly high radium content of abyssal sediments, especially of Red Clay and of Radiolarian Ooze, first discovered by Joly of Dublin nearly half a century ago, remained unexplained, until a team of workers from Scandinavia and Vienna took up the problem 20 years ago. The results proved that the scarcity of radium in sea-water, about one sixth to one seventh of the equilibrium value dissolved uranium, was due to a precipitation of the intervening element ionium on the deep-sea floor, where it gives rise to radium. This opens a possibility of age-determinations from the known rate of decay of ionium, viz. to ½ in 83,000 years to ¼ in 166,000 years, etc. A chronology of the last 300,000 to 400,000 years appeared possible from radium measurements in layers at given distances from the sediment surface. Early attempts according to this method made by Piggot & Urry appeared to conform with theory. Later measurements by Kroll in Göteborg on a much more extensive material from the "Albatross" cores, have proved the distribution to be much

more complicated, possibly due to radium leaving its mother element ionium through a diffusion process. Anyhow approximative age-determinations, based on the radium content near the sediment surface have given rates of sedimentation as low as 1 mm. or even less in 1,000 years for the central Pacific Ocean.

A perfected method for uranium determinations, elaborated by Hecht in Vienna in collaboration with Kroll, has shown that the high radium concentration found in the surface of Pacific Red Clay, up to 50 units of the 12th decimal place, cannot be explained as due to uranium-supported radium. The uranium content is rarely more than a few units of the 6th decimal place corresponding to only 1 unit of the 12th decimal place for radium.

Thanks to the recent work by E. Picciotto in Brussels, adopting the photographic method, it has for the first time become possible to measure the concentration of *ionium* and of its isotope *thorium* in deep-sea deposits, a technique which may open a more certain way towards radioactive age-determinations.

Summing up the results found from these different methods, we may say that the sedimentation rate in the equatorial Pacific Ocean is of the order 1 to a few mms in 1,000 years for Red Clay, and twice to four or even five times higher for calcareous ooze. One of our longest Red Clay cores from the central Pacific Ocean of 15 meters should, therefore, with its lowest strata carry us back 15 to 20 million years in time.

However, studies of the East Pacific cores by Arrhenius and of the Radiolarians in the deep-sea sediments by Riedel have proved that there are cases when the rate of accumulation of sediment assumes *negative* values, owing to the upper layers having been carried away by eroding bottom currents laying bare older sediments.* This also may lead to radiolarians of Tertiary age becoming mixed in the same layer with more recent ones.

The most surprising results from the soundings of the sediment thickness made by Weibull's reflexion method, was the small thickness of the sediment layer found in the Pacific and the Indian Oceans, rarely over a few hundred metres, whereas in the Atlantic Ocean between Madeira and the Midatlantic Ridge Weibull found a maximum thickness of over 3,400 metres. The low values from the other oceans have recently been confirmed through measurements by the refraction method, carried out from American and British expeditions. These surprisingly low values are only a fraction of the theoretical thickness computed by Kuenen and others. For this large discrepancy no satisfactory explanation has so far been advanced.

* Already reported from the NW Atlantic Ocean by M. Ewing & Co-workers.

Owing to a faulty construction of the clockwork used with the "Albatross" geothermometer only two dependable values were obtained for the geothermal gradient, both from the equatorial Pacific Ocean, viz. an increase of 1°C in 22 and in 26 metres, i.e., considerably higher than the average value for the continents, whereas for general reasons one would have expected a lower value. A third value found in the beginning of 1948 in the E. Indian Ocean, which at that time appeared suspiciously high, was 1° in 4 metres.

High values of the geothermal gradient in deep-sea sediments have recently been found also by Revelle on the "Capricorn" Expedition, where a thermo-electric geothermometer of smaller depth range, due to Bullard, was used. The high values for the geothermal current computed from these measurements is highly puzzling. It may possibly be explained through a wide-spread although latent volcanism of the deep-sea floor, for which much independent evidence exists.

Regarding diagenetic changes in the deep-sea sediments Arrhenius has proved induration due to silica, diffusing from dissolving silica-skeletons to occur in cores from the Eastern Pacific. Also the diffusion of manganese may lead to a formation of surface crusts, as has been observed already from the Challenger Expedition. That a considerable vertical migration of various components in the sediment takes place is evident. Special interest adheres to the cases of *deep-sea sand,* such as we from the "Albatross" found in great depths, especially in the Romanche Deep in the equatorial region of the Atlantic Ocean. There coarse sand, consisting of angular fragments of mafic rocks, testified to a contribution to the sediments from the substratum. The great ruggedness of the deep-sea floor indicates that tectonic forces are active, leading to differential movements at which a crushing or mylonisation of the rock material may well occur. Other instance of deep-sea sand obtained in cores taken further west in the same ocean indicate a quite different origin, viz. from the coastal plateau of a continent or of a large island. Also a displaced shallow-water benthonic fauna and fragments of vegetation remains speak for a continental or island origin. The great distance of the place of the find, some 500 nautical miles from the coast of S. America, makes the transportation problem highly puzzling.

These few instances of the results found from extensive investigations of the "Albatross" cores prove how extremely rich in promising results is the new science of deep-sea geology in the development of which American and British investigators, like Ewing, Tolstay, Shepard, Phleger, Bullard a. o., have taken such a prominent part. Here obviously is a field for international cooperation like that established half a century ago with the International Council for the study of the

shallow and economically important parts of the seas round NW Europe. It is to be hoped that the "Joint Commission of Oceanography" set up by the UNESCO at the Brussels meeting in 1951, aided by the new founded "Deep Sea Journal," will lead to such an organization of the work in great depths. The Pacific Ocean is at the same time the vastest and the most interesting field of such research. It is my hope that this congress will adopt a resolution recommending international cooperation in this vast new field of scientific research.

SOME CHARACTERISTICS OF SEA WATER STRUCTURE

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Introduction

Recent examination of nearly two thousand serial observations in oceanic and coastal waters of the northeast Pacific Ocean has revealed several general characteristics in the structure of the water in these seas. Sea water occurs in zones of appreciable thickness with respect to each property, and within each zone the measure of the property tends to be a simple function of the logarithm of depth.

These concepts of structure are illustrated in Figure 1 with simple examples of salinity and temperature data. These have been plotted in the usual way as natural functions of depth (natural-plot) and as functions of the logarithm of depth (log-plot). These illustrate the nature of the transformation. It is evident that there are two water masses represented by the more homogeneous layers. These may be designated as the *upper* and *lower zones*, which are separated by a transition or *boundary zone*. It is also evident that within each zone the values of the properties are linear functions of the logarithm of depth (logarithmic gradients).

Examination of Oceanographic Data

The properties of the water may be observed at a series of depths from the surface downwards (serial observation). From such data the vertical structure is usually illustrated by plotting the values of the properties as a function of depth and interpolating a smooth curve through the points. This procedure is becoming more precise as instruments, such as the bathythermograph, are being developed to make continuous records while being lowered in the sea. The distribution of properties in a locality is observed by making serial observations at a number of positions in as short a time as possible (synoptic survey). From these data plans and vertical sections are drawn, showing interpolated isometers of the sea water properties.

In this analysis of the data from serial observations, the values of the properties were plotted as functions of the depth on semi-logarithmic graph paper, and the points were joined by straight lines. In general, small deviations were ignored and the best straight line was drawn

through groups of points. It was usual to examine the deep zone first, since it was the easiest to interpret. Then the upper zone was located. The remaining points fell in the boundary zone, which was interpreted in one or more segments as indicated by the data. Although this procedure is extremely simple, there are opportunities for differences of opinion, as in any method of interpretation. Therefore, it is necessary to adopt certain conventions to insure uniformity.

The surface observation was plotted at unit depth (0.1, 1, or 10). This is justified because the surface sample in a serial observation is invariably taken at some depth ranging from one-tenth to ten meters.

Simple Structure

Simple structure occurs when there is a regular alteration of water masses and transition layers. These appear as nearly homogeneous zones and boundary zones. There is a considerable variety of these simple structures including the types shown in Figure 2. Although most of the data indicated that there were three zones present, there were cases where either the upper or deep zones were absent or had become homogeneous. However, all of these examples indicate a simple structure involving a single water mass, or one well-defined mass overlying another. This is the basic structure, and all others are modifications or derivatives of it.

In the case of the temperature no distinction is made in the classification between a negative gradient (temperature decreasing with depth) and a positive gradient (temperature increasing with depth).

Complex Structure

Certain complex structures such as those shown in Figure 3 cannot be reduced by approximation to simple structures. In these there are two or more segments in the boundary zone in which the successive gradients of properties continue to increase, or decrease, rather than alternate in slope. In the limit, where there are many such segments, the log-plot appears as a curve, and the straight line rule cannot be readily applied. However, in the majority of cases, there are no more than two or three such segments, and the interpretation is obvious.

Conventions

There were instances, particularly in the boundary zones, where the data could be interpreted in several ways, as shown in Figure 4. Where three or more points fall on a straight line, as shown in the boundary zone in structure A, there is no doubt about the interpretation. Similarly the two points in the boundary zone of structure B define the position and slope of the boundary but are no guarantee that it is a logarithmic gradient. The boundary zone in structure C may be interpreted as having three points, as shown by the solid line, or as having only one point, as indicated by the dashed lines. Evidently the true

structure is between these limits and cannot be better defined from the data. Structure D illustrates another indeterminate boundary that may be interpreted as having two or one point. In structure E it is evident that there is a boundary because of the discontinuity between the upper and lower zones. However, since data in the zone are lacking, it may be interpreted by any gradient between the limits of the dashed lines.

The conventional interpretations are indicated by the solid boundary zones in the figure, and the data are divided into two groups. The first includes all zones such as A and C where the gradient is defined by three or more points, and the probable error can be determined from their scatter. The suitability of the concept of logarithmic gradients is based on such data. Secondly, all zones defined by two points or less are grouped together because the plot cannot be analyzed statistically, and there is usually some doubt about the interpretation. These two-point zones provide no proof of the validity of the concept. They may be regarded as supporting evidence because they afford no contradictions.

Probable Error of the Log-Plot

TABLE I

SUMMARY OF THE EXPERIENCE OF FITTING THE LOG-PLOT TO SERIAL OCEANOGRAPHIC DATA

	Zones			
	UPPER	BOUNDARY	LOWER	TOTAL
	TEMPERATURE			
Zones examined	225	436	207	878
Zones defined by three or more points	111	286	163	424
Probable Error (T°C)	0.06	0.09	0.06	
Zones defined by two points or less	114	150	44	454
	SALINITY			
Zones examined	244	384	209	837
Zones defined by three or more points	144	191	196	531
Probable Error (S‰)	0.07	0.08	0.04	
Zones defined by two points or less	100	193	13	306

A summary of the general experience is shown in Table I. Blocks of winter and summer data were taken from serial observations in the ocean, well offshore, and from Georgia Strait, which is an enclosed sea dominated by a large river. This analysis includes only a small part of the data that have been studied by this log-plot method.

The number of points in each structure is limited by the intervals of the serial observation, and could always be fitted by a plausible log-plot. More data could be taken from bathythermograph observations and in the majority of cases confirmed the log-plot interpretation. However, further examination of bathythermograph data, as summarized in Table II showed that there was a small proportion of structures that were not logarithmic. Generally these plots appeared as long curves, somewhat similar to an inverse function of the depth. As will be discussed later, these are probably immature gradients which eventually will become logarithmic.

TABLE II

SUMMARY OF THE EXPERIENCE OF FITTING THE LOG-PLOT TO BATHYTHERMOGRAPH DATA

	Zones		
	UPPER	BOUNDARY	LOWER
Zones examined	593	1329	543
Logarithmic gradients	590	1169	515
Proportion (%)	99.5	88.2	94.9

Step Structure

Considerably more than half the zones were defined by three or more points. In the deep zone the log-plot is the best representation of the data within the limits of error of the observations. The scatter of points increases towards the surface, in the boundary and upper zones, to something more than twice this limit of error.

The reason for this increasing scatter towards the surface was sought in an examination of continuous data records from the salinity-temperature-depth recorder and the bathythermograph. These revealed *step-structure* as illustrated in Figure 5. The structure within each zone consists of a number of small, nearly homogeneous layers, separated by narrow boundary zones. The mean slope through this step structure is the logarithmic gradient defining the major zone.

The same situation observed in the usual way with sea water sampling bottles at discrete depths would indicate a random scatter along the mean gradient. Such serial observations do not define the structure completely, and the only possible interpretation is the logarithmic gradient most nearly approximating the general slope in the zone, as defined by the dashed line in the figure.

This interpretation stresses the principal structure, ignores the small variations, and accepts the error implied in the scatter of the points.

However, in most cases, there is considerable short-term fluctuation in the fine structure and even in the dimensions of the boundary and upper zones. Examination of several series of hourly bathythermograph observations, such as illustrated in Figure 6, indicated that this fine structure was transient, that the thickness and depth of the major zones varied with time, but the principal characteristics such as the gradient and range of values of the properties in the major zones were constant. It is evident that the fine detail is not significant, within the limits of the usual serial observation, and that the structure is adequately defined by the simplest interpretation.

From these considerations it may be concluded that a zone is a layer of water in the sea where the gradient of a property is a single linear function of the logarithm of depth, within small limits of error.

Structure of Independent Properties

Figure 7 illustrates the temperature, salinity, density (σ_{STP}), and dissolved oxygen structure from a single serial observation, which is representative of the general experience. The structure with respect to each property is readily interpreted by the log-plot technique but the structure do not coincide.

TABLE III

SUMMARY OF EXPERIENCE OF FITTING THE LOG-PLOT TO SERIAL OCEANOGRAPHIC OBSERVATIONS IN THE DEEP ZONES OF THE NORTHEAST PACIFIC OCEAN

	ZONES EXAMINED	PROBABLE ERROR
Temperature	400	±0.047
Salinity	400	±0.015
Density (σ_{STP})	400	±0.013

Sufficient examinations, as shown in Table III, have been made to prove that the log-plot fits the density structure as well or better than it fits the temperature or salinity structure, but as shown in Figure 7, the structure is a combination of these. The distribution of dissolved oxygen is also found to be logarithmic, but the structure is distinct from these others. Similar conclusions were indicated by the cursory examination of some dissolved phosphate data.

Evidently the structure with respect to each independent property is unique. The limits of the temperature zones are different from the limits of the salinity zones, and the dissolved oxygen structure is different from both. This is reasonable since the advection and dissipation of these properties are independent functions.

Formulation of Structure

This experience indicates that the value (P) of a property at a depth (z) in the sea may be expressed by

$$P = k \log z + c \tag{1}$$

where k and c are constants within the limits (z_1 and z_2) of a particular zone. However, there is some variation in the data and other curves of similar form were examined to determine if as good a fit could be obtained. Curves of the forms

$$P = k \log (z_2 - z_1) + c$$
$$\log P = kz + c$$
$$\log P = k \log z + c$$
$$\log P = k (\log z_2 - \log z_1) + c$$
$$\log P = k (z_2 - z_1) + c$$
$$\log P = k \log (z_2 - z_1) + c$$
$$P = \frac{k}{z} + c$$
$$P^2 = \frac{k}{z} + c$$
$$P = \frac{k}{z^2} + c$$
$$P = \frac{k}{z_2 - z_1} + c$$
$$P^2 = \frac{k}{z_2 - z_1} + c$$
$$P = \frac{k}{z_2^2 - z_1^2} + c$$

were examined. However, only Equation 1 provided a simple relation, and subject to further discussion, it is accepted as the most plausible expression of the facts.

The slope of the gradient (k) may be evaluated from the data as

$$k = \frac{P_2 - P_1}{\log \frac{z_2}{z_1}} \tag{2}$$

where the subscripts refer to the values at the upper and lower limits of the zones.

The constant (c) may be evaluated by setting $z = 1$ in Equation 1, whence

$$c = P' \tag{3}$$

where P' is the abscissa of the gradient extrapolated to unit depth.

Characteristics of the Log-Plot

It is important to realize that the log-plot is a technique for interpreting the sea water structure from serial observations. It is realistic

because it represents the actual structure of the sea as observed. It has many advantages in the study of regime and mechanism in oceanographic systems, because it emphasizes many phenomena which are readily overlooked in a natural-plot.

Linear Interpolation of Data

When data from serial observations are plotted on a natural depth scale, the gradients are usually interpreted by a free-hand continuous curve as shown in Figure 1. In many cases this is subject to dispute, and in any case it does not define the limits of the zones. Furthermore, the structure in the zones near the surface is lost in the small depth scale, which is necessary to include the deep zones where very little structure is evident.

The log-plot provides a conventional interpretation of serial oceanographic data which is realistic, and acceptable. The linear interpolation between the elements of data, and the unmistakable definition of the zones are ideals which have long been sought. Furthermore, the display of the data coincides with the degree of interest in most oceanographic studies, because it emphasizes the structure in the zones near the surface, while retaining the definition of the deep zones, and the continuity of the whole structure.

Demarkation of Zones

In the log-plot the limits of each zone are sharply defined by the intersections of the straight lines. This characteristic allows a more critical examination of the data than any other technique of interpretation. Furthermore, it is not necessary to have continuously recorded data to determine the limits of a zone; it is only necessary to have enough observations to define the gradients of the properties.

The intersection of the gradients at the limits of the zones suggests that the structure is discontinuous at these points. There is some doubt whether these limits are real discontinuities or not. There is some lag inherent in the S.T.D. and bathythermograph, which are the best recording instruments available, so that the slight rounding of the corners shown in their records are not altogether reliable. Most records show a small step at the limits of the zone, such as illustrated in Figure 5, but the significance of this has not been determined.

Index Salinity

In the examination of these data it has been noted that the salinity at the upper limit of the more homogeneous zones and sub-zones tends to remain constant along the line of flow. For this reason, it is termed the *index salinity*. However, the salinity at the upper limit of the boundary zone is not constant. On examination of the data in Georgia

Strait, as shown in Figure 8, it was noted that the index salinity recurred within $0.2^0/_{00}$ S at the upper limit of the zone at every station in the vicinity of the Fraser River. The plan and cross-sections of the data were interpreted by contours of depth of this index. This illustrates the structure of the region much more realistically than the usual contours of arbitrary salinity values.

Indication of Errors

In the course of plotting the data occasional lone points were found that deviated from the log-plot defined by other points above and below. On checking the calculations and data, errors were found, or were possible, in practically all cases. The accumulation of such experience has led to the policy of discarding single observations that do not coincide with the log-plot.

Calculation of Dynamic Height

The calculation of dynamic height requires the mean density through the column of water defined by a serial observation. The usual procedure is to compute the mean density of each sample and integrate with respect to depth. Having established the validity of the log-plot as the best representation of the data, it is permissible to reduce the labour by calculating the mean density in each whole zone.

Where the limits of the zone from the surface downwards are z_1 and z_2 the mean density $(\bar{\sigma})$ in a zone may be written

$$\bar{\sigma} = \frac{1}{z} \int_{z_1}^{z_2} \sigma dz \tag{4}$$

where σ is the density in situ of the water at the limits z_1, z_2, etc., expressed as $(\rho - 1)1000$. But it has been shown that

$$\sigma = k \log z + c \tag{1}$$

Setting this in Equation 4

$$\bar{\sigma} = \frac{k}{z} \int_{z_1}^{z_2} (\log z + c) dz$$

$$= \frac{k}{z} \left[z_2 \left(\log z_2 + \frac{c}{k} - 1 \right) - z_1 \left(\log z_1 + \frac{c}{k} - 1 \right) \right]$$

in which k and c may be evaluated in terms of the data as shown in Equations 2 and 3. Whence the expression becomes

$$\bar{\sigma} = \frac{\sigma_2 - \sigma_1}{\log z_2 - \log z_1} \left[z_2 \left(\log z_2 + \frac{c}{k} - 1 \right) - z_1 \left(\log z_1 + \frac{c}{k} - 1 \right) \right] \tag{5}$$

It is not necessary to calculate σ at every observation, rather the mean values of temperature and salinity may be evaluated similarly to Equation 5, and the mean value of σ computed from them in the usual way. Having evaluated $\bar{\sigma}$ in each zone, these may be treated in the usual manner to discover the dynamic height.

This procedure reduces the number of calculations and is probably more accurate than the usual computations based on linear interpolation between observations.

Deductions Regarding Mechanism and Structure

Origin and Behaviour of Water Masses

It has long been recognized that sea water occurs as masses, each having characteristic values of temperature, salinity or other properties. Usually these water masses are generated in some locality such as the Arctic, the Tropics, estuaries, etc. As they move out from the sources they over-ride the more dense, or under-run the lighter waters that are encountered enroute.

It is supposed that a water mass must be subject to internal turbulence if it is moving at an appreciable rate, since the Reynold's Number in all natural flows far exceeds the threshold of turbulence. Each water mass tends to pursue its own course and speed and so is independent to some extent. Consequently, there is a region of boundary turbulence resulting from the shear between water masses.

Turbulence, regardless of its course or location, may be regarded as the random exchange of fluid elements normal to the plane of motion. In the vertical direction it is statistically similar to diffusion, and results in exchange of properties through a zone.

This is indicated by the derivatives of the observed relation (Equation 1)

$$\frac{\partial P}{\partial z} = \frac{k}{z} \tag{6}$$

where z refers to the total depth from the surface. This implies that the limit of every zone is virtually at the sea surface.

The slope constant (k), as shown in Equation 2, depends only on the thickness of a zone, and the difference of the values of the properties at the upper and lower limits. It describes the physical character of the zone at the instant of observation, and is not, by itself, indicative of the mechanism by which the zone is created. It is possible to imagine a situation where there were two water masses with identical turbulence (energy) characteristics. An upper, boundary, and lower zone would be formed, each having a different gradient of properties. The mechanism of mixing is revealed by the form of the relation, and the source of the exchange is truly at the surface.

On further consideration, it is evident that in any case the source (or sink) of the property may always be referred to the surface, since the process of mixing is continuous at all depths, even though the rate may vary.

There is a temptation to associate each zone with a region of a particular degree of turbulence. For example, the nearly homogeneous zones might represent the region of internal turbulence in a water mass, while the boundary zone would represent the extent of the added turbulence induced by the shear between water masses. However, this would imply that the structure at a single position was an expression of the energy characteristics of the system. The structure reveals the mechanism, and is surely a result of the energy characteristics, but the energy distribution can only be expressed by the difference between structures. Furthermore, there is no quantity of time in the definition of the structure (Equation 1) and finally it has been shown that the slope of the gradient can be readily explained by the dimensions and distribution of the water masses.

It is concluded that each zone is an independent structure, behaves as if it were the only zone present, and as though its source or sink were at the surface. This concept is implied in the evaluation of the constant (c) in Equation 3. It is supposed that there is a surface layer of unit thickness, and of constant properties (P) and that it is continually being renewed, so that it acts as an inexhaustible source, or sink.

In the simple case where the water masses are not affected by external factors such as insolation or precipitation, the structure in each zone tends towards homogeneity. But at the same time the conditions at the limits of the zones are being renewed by transfer of water from elsewhere. Each zone is a source and sink for its neighbours, so that one zone cannot become homogeneous while the character of its neighbours remains unchanged. Rather the gradients in the several zones tend to become congruous, and then the whole structure tends to degenerate towards homogeneity. This process is well illustrated by the sequence of salinity observations shown in Figure 8. The step structure is very apparent near the mouth of the Fraser River, but with increasing distance the steps become less and less apparent as the structure becomes mature.

The tendency towards homogeneity can only be opposed by the introduction of new sources of properties. For example, the surface water may be heated diurnally so that a gradient of temperature, as shown in Figure 9A, is formed. During the night the surface is cooled, or the zone is mixed to homogeneity by the wind so that a single step structure is formed as in Figure 9B. The effect of further heating and

homogenizing is indicated in structures C and D. Eventually a step structure such as E may result. It is important to realize that each advection must tend toward congruity as it becomes deeper, and more mature, because once removed from the source at the surface no further advection can take place, and the homogenizing tendency proceeds unchecked. Thus step structure degenerates towards a simple logarithmic gradient at maturity. Obviously step structure with respect to any property can occur at any depth or zone where a new source of sink is provided. Excellent examples of such deep phenomena occur in the margins, and confluences of the great ocean currents.

The Meaning of Structure

Studies now in progress indicate that each structure is a historical record of the influences and processes which the water masses have experienced in the sea. These are too extensive for general discussion here, but one simple example may be cited for illustration.

The origin of the minimum temperature zone in the northeast Pacific Ocean has been made apparent by the seasonal sequence of structures shown in Figure 10. In March, towards the end of winter the upper zone waters are isothermal and at a minimum temperature, somewhat colder than the top of the deep zone. As the season advances the surface waters are warmed by vernal heating. This process may be regarded as the accumulation of heat from successive afternoon effects and wind mixing, as illustrated in the sequence of structures in Figure 9. The warm upper zone continues to increase through the summer to mid-September. However, in the autumn the surface cools and the violent winter storms mix the waters. In this process the upper zone cools but continues to become deeper. Eventually its boundary intercepts the remnants of the previous winter boundary, and finally the characteristic late winter structure is formed.

Conclusion

It is evident from these remarks that the concepts of zones and logarithmic structure are at least plausible, and the consequent technique of the log-plot affords a new and powerful oceanographic tool. The present examinations have been limited to the coastal and oceanic waters of the northeast Pacific Ocean, but it appears that the principles involved should be general. However, such a conclusion must await study of data from other places, and examination of the ideas by other oceanographers. It is hoped that such studies will enrich the present experience.

ILLUSTRATIONS

FIG. 1.—Idealized examples of simple salinity and temperature structures showing the characteristics of the natural-plots and log-plots.

FIG. 2.—Types of simple temperature and salinity structure. There is an upper and lower zone separated by a boundary zone. Either the upper or lower zone may be absent or they may be congruous.

FIG. 3.—Types of complex structure where the successive gradients of properties in the boundary zone continue to increase or decrease from segment to segment.

FIG. 4.—Method of analysis of the logarithmic gradient in the boundary zone. The conventional interpretation is indicated by the solid lines. Other possible interpretations are indicated by the dashed lines.

FIG. 5.—Bathythermograph, Latitude 50° 24′N, Longitude 131° 34′W, 0304, 7 August, 1951. This illustrates step structure whose mean gradient approximates a logarithmic gradient within small limits of error. The circled points represent the standard depths that would have been observed in a serial observation.

FIG. 6.—Log-plot from a series of half-hourly BT observations in Juan de Fuca Strait, Latitude 48° 13.8′N, Longitude 124° 09′W, 4 July, 1952. These demonstrate that the hourly variation in the fine structure, and in the depth and magnitude of the boundary zone, are greater than the deviation from the best straight line through the points.

FIG. 7.—Log-plots of the serial observations at Latitude 54°21′ N, Longitude 140°05′ W, on 0730, 10 August, 1950. These show that the structure with respect to each independent property is unique.

FIG. 8.—Application of the concept of index salinity in logarithmic structure to the illustration of oceanographic data.

FIG. 9.—Idealized temperature structures illustrating the formation and degeneration of step structure due to diurnal heating and cooling in the upper zone.

FIG. 10.—Idealized sequence of structures illustrating the annual temperature cycle in the upper zone in the northeast Pacific Ocean. (Reference . . . DOE)

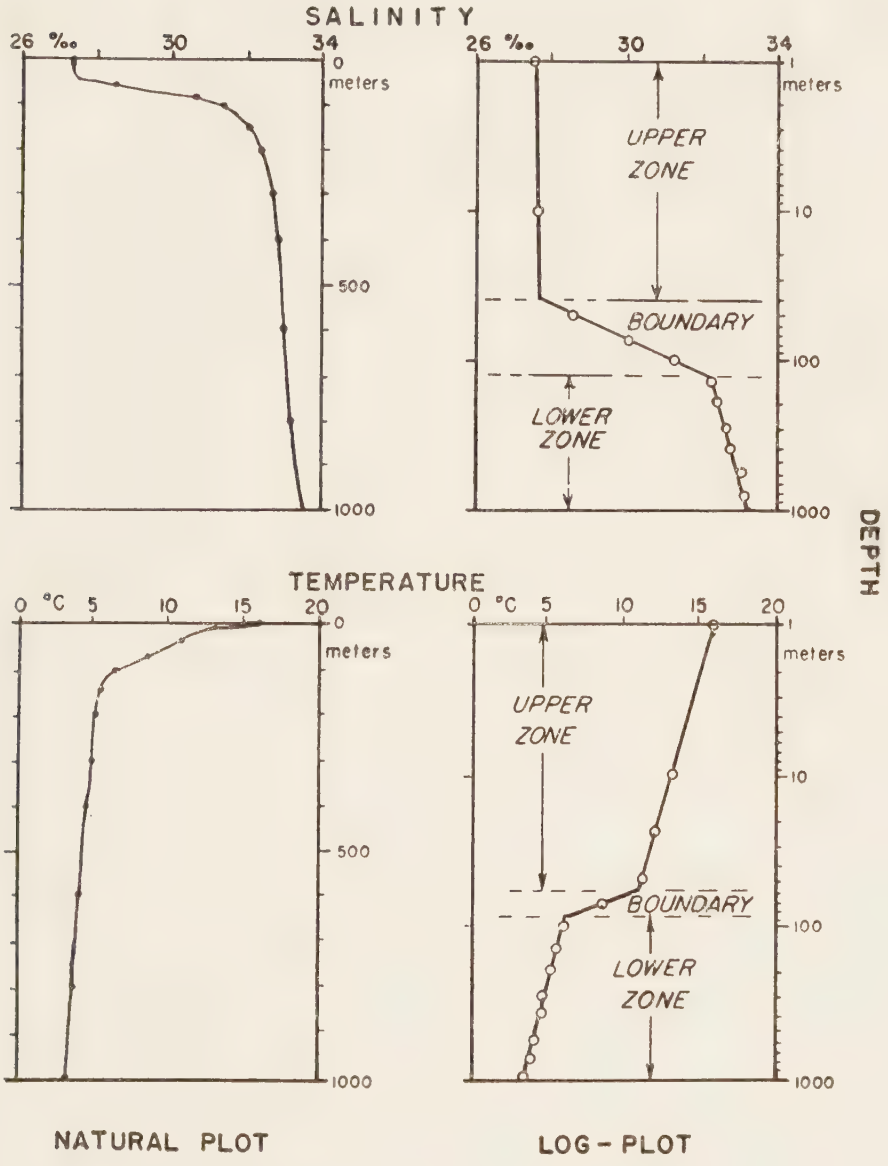

SALINITY
26 ‰
30
34
0
meters
500
1000
UPPER
ZONE
BOUNDARY
LOWER
ZONE
100
10
1
DEPTH
TEMPERATURE
0 °C
5
10
15
20
NATURAL PLOT
LOG - PLOT

FIGURE 1

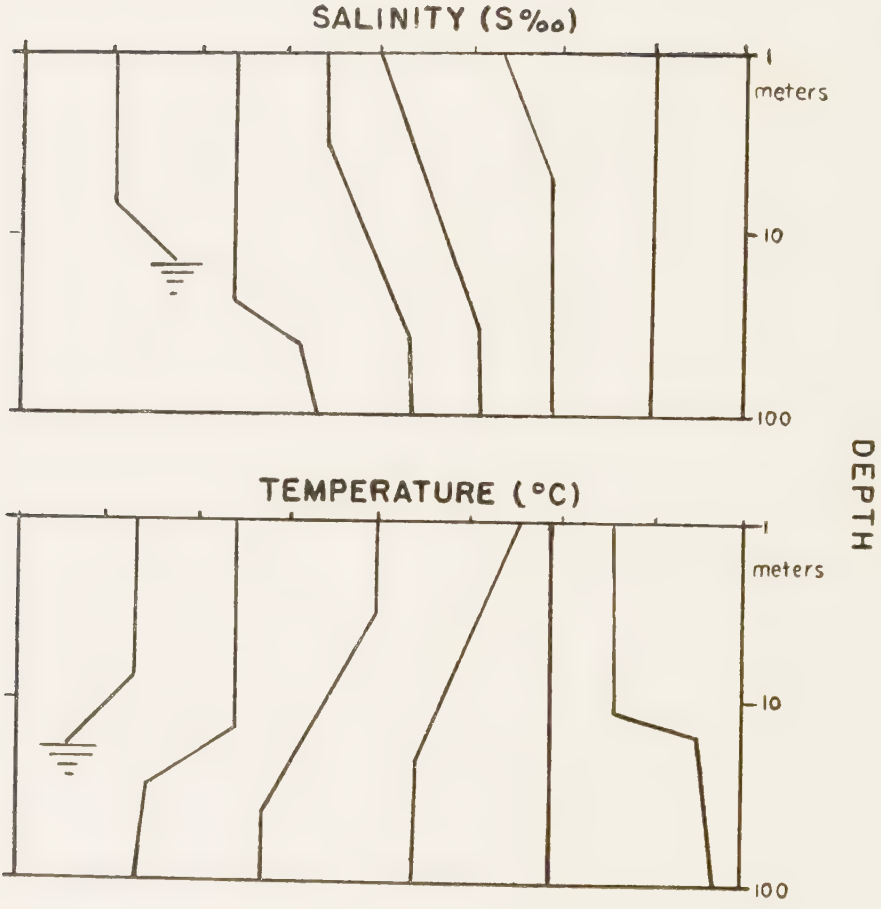

SALINITY (S‰)
1
meters
10
100
TEMPERATURE (°C)
1
meters
10
100
DEPTH

FIGURE 2

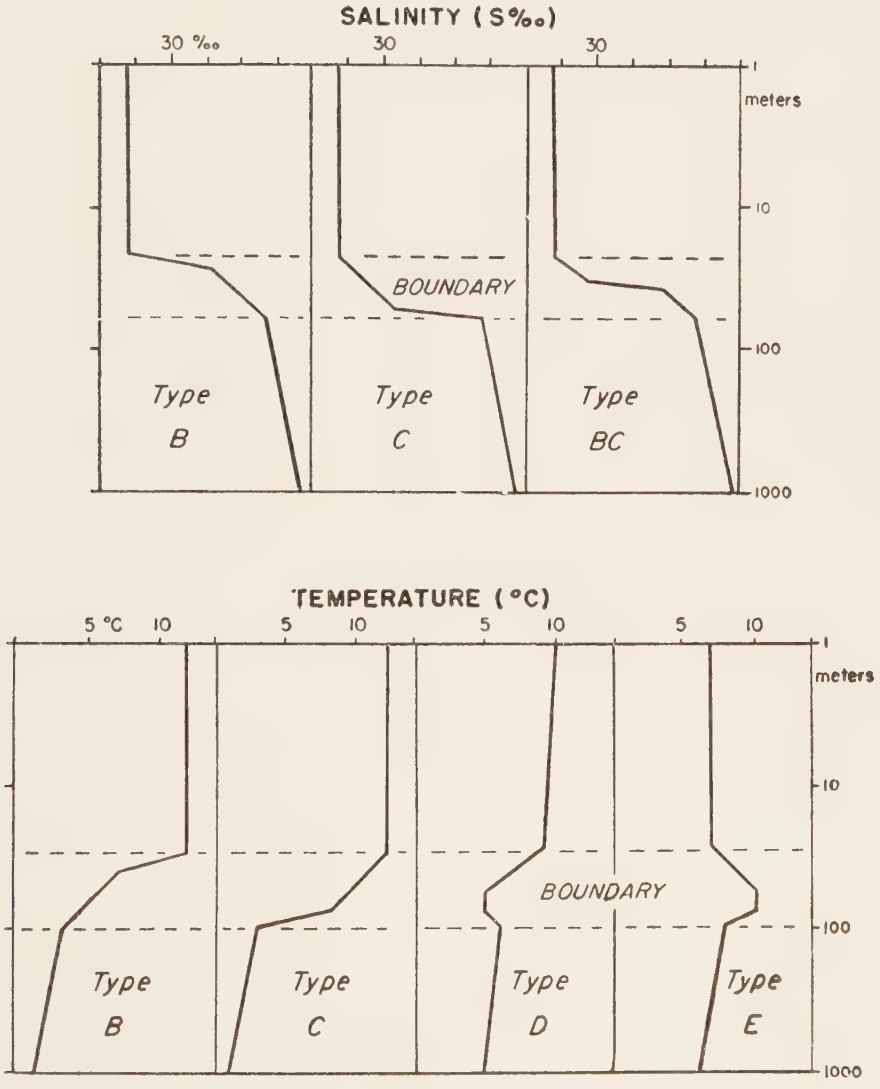

SALINITY (S‰)
30 ‰
30
30
1
meters
10
100
1000
BOUNDARY
Type B
Type C
Type BC
TEMPERATURE (°C)
5 °C
10
5
10
5
10
5
10
1
meters
10
100
1000
BOUNDARY
Type B
Type C
Type D
Type E

FIGURE 3

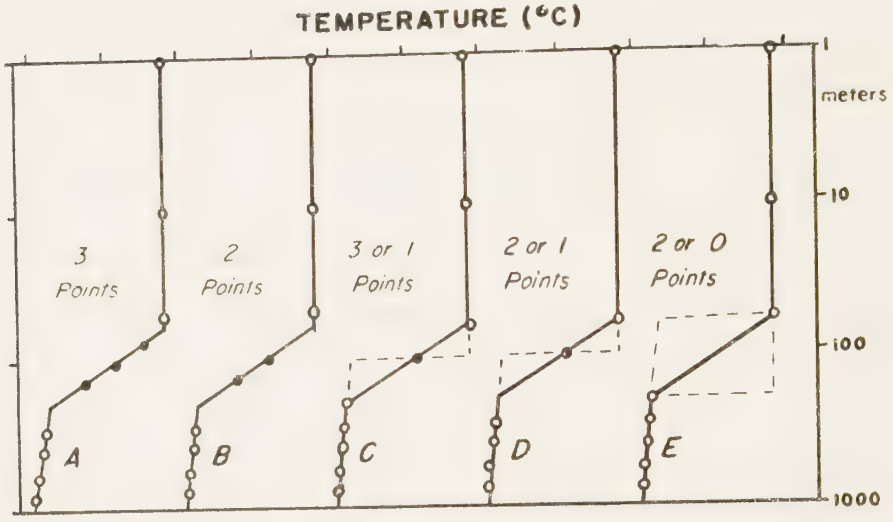


FIGURE 4

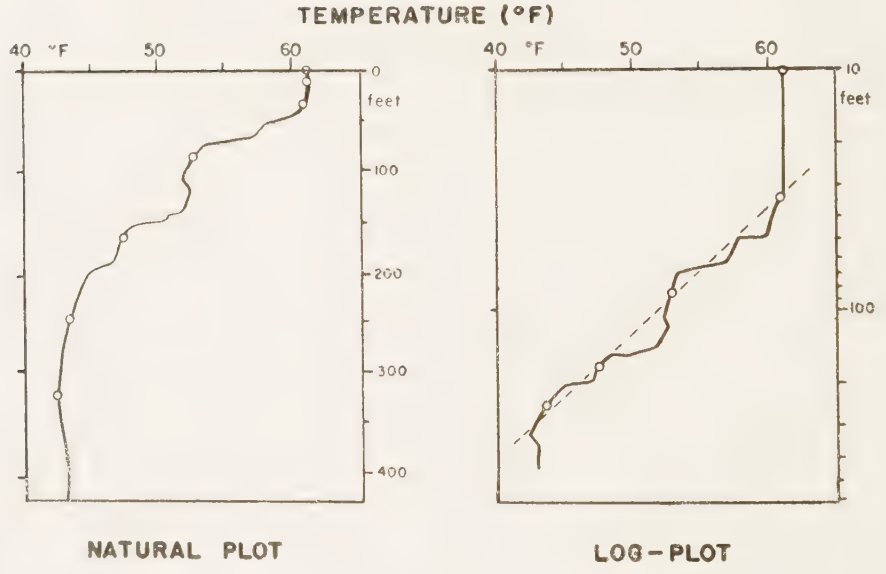


FIGURE 5

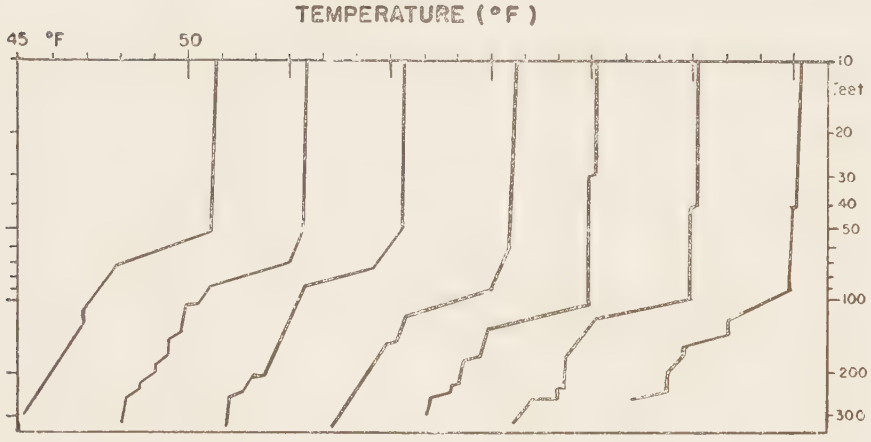


FIGURE 6

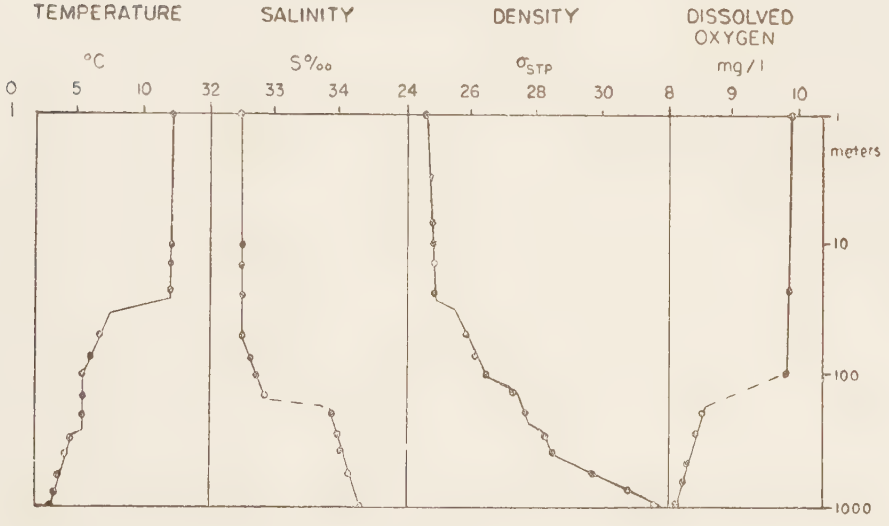
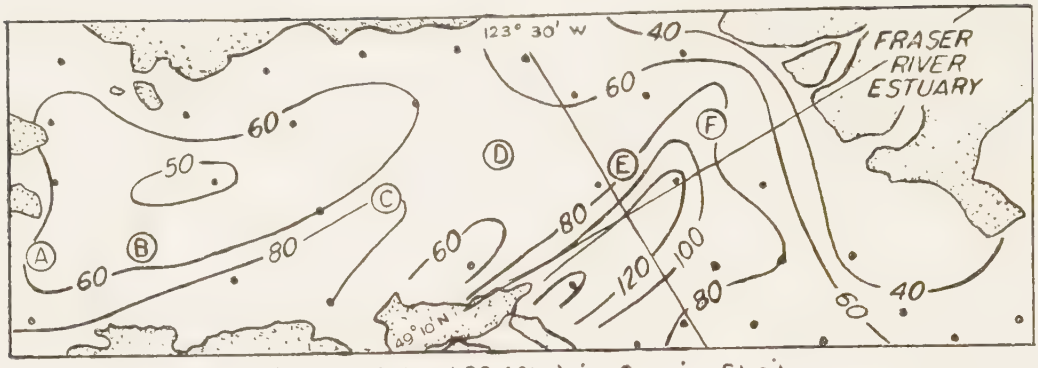
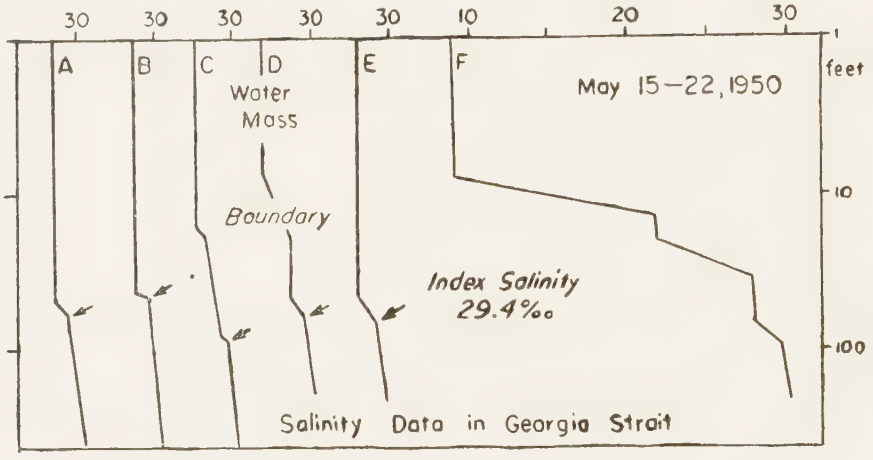


FIGURE 7



Depth (feet) of index salinity (29.4‰) in Georgia Strait



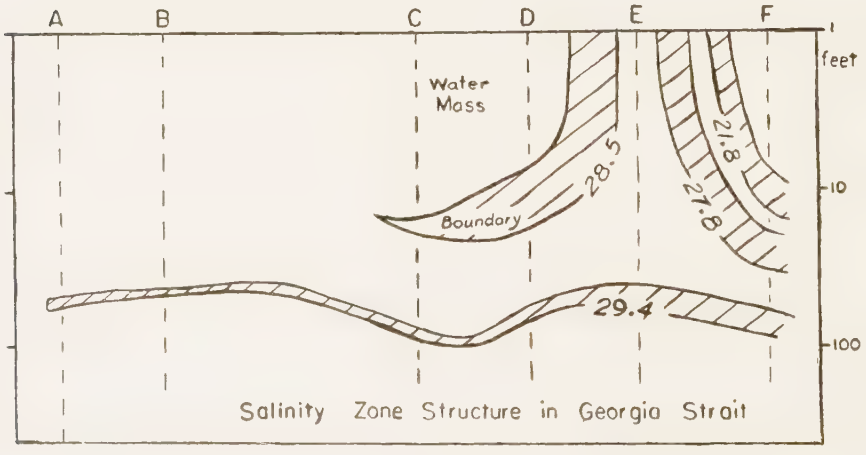


FIGURE 8

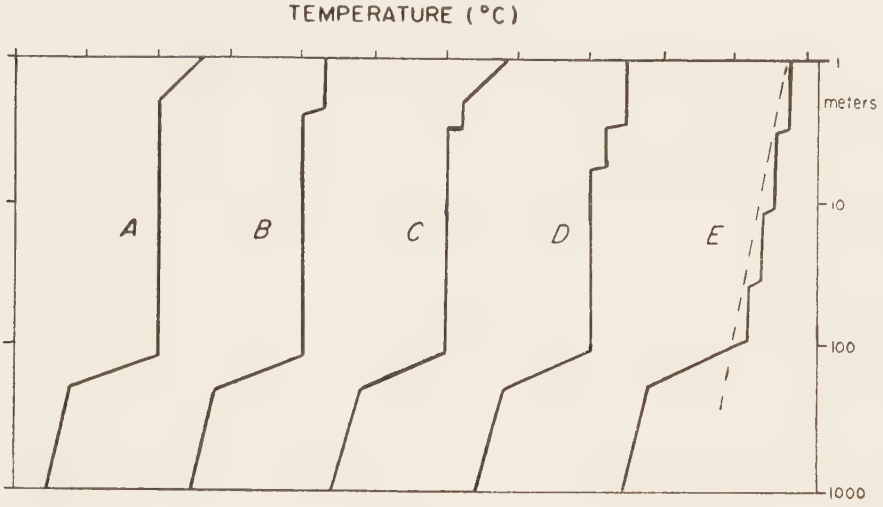


FIGURE 9

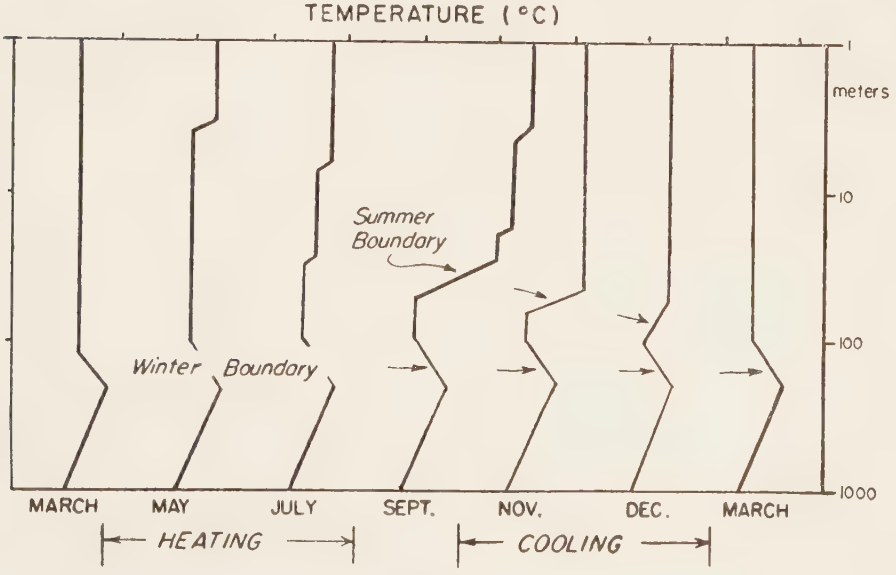


FIGURE 10

ON THE CIRCULATION IN THE NORTH PACIFIC IN RELATION TO PELAGIC FISHERIES

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Tokyo University of Fisheries
Kurihama, Yokosuka City, Japan

On the charts plotted by the author, the semi-permanent boundaries of the water masses (fronts) in the Northwest Pacific adjacent to Japan, i.e. the Coastal Fronts, Oyashio Front (Polar Front or Subarctic Convergence), Kuroshio Front, Warm and Cold Fronts in the Japan Sea, Subtropical Convergence, Equatorial Counter Front, Continental Front are shown in relation to pelagic fisheries grounds of tuna, skipjack, Pacific saury and whales (Fig. 1). Briefly we can summarize the following three types of pelagic fishing grounds on the above hydrological point of view:

(1) Those produced by the planktonic livings and fishes in the compressed zone of the optimum water temperature due to mere convergence (e.g. the skipjack fishing grounds in the northern boundary zone of Kuroshio and the Pacific saury fishing grounds near the Oyashio Front).

(2) Those produced by marine organisms due to the upwelling of the water of rich nutrients in the deeper layer obeying Nathansohn's theory (e.g. the fishing grounds of sardine, squid, yellow-tail, bluefin tuna, mackerel, etc., or some varieties of this type), indicating dense concentrations near the coastal front and the fishing grounds on the eddies around the islands or capes (mackerel, flying fish, etc.) and around banks (skipjack, tuna and mackerel, etc.).

(3) The combined fishing grounds of (1) and (2) types (e.g. the marginal convergence of the upwelling area at the front of the cold water such as the fishing grounds of the albacore, whales, Pacific saury, etc.).

Further we will inspect the oceanographic structure in the North Pacific by means of the nucleus method. The depth of the intermediate water S min. and the value of that depth during the period 1931–41 were plotted in Figures 2, 3 and 4.

The intermediate water in the Northwest Pacific may be considered as the carrier of the rich nutrients which are produced in the seas of high latitudes and fertilizer resulting in the high production in the seas of lower latitudes. The prevalence of the cold water circulation,

i.e. the prevalence of the intermediate water, was associated with the anomalous Kuroshio conditions in recent years (1935–47).

The northern intermediate water appears to extend conspicuously to south along the Japan Trench and invades in the sea basin south to Japan. Going south further, it descends to its deepest layer beneath the depth of 800 m. in the sea-region at about 34–24°N. with the salinity of 34.0–34.2 $^{0}/_{00}$ and rises again gradually up to the depth of 200 m. at about 5°N., showing the increase of salinity to 34.5 $^{0}/_{00}$.

The northern and southern intermediate waters collide with each other in the zonal region of the latitudes of 12°–2°N., lying at about the depth of 200 m. for the former (the Northern Intermediate Water) and at about the depth of 800 m. (600–1000 m. depth) for the latter (the Southern Intermediate Water).

Accordingly in that region the vertical distribution of salinity shows the double minimum which is produced by the stratification of the southern intermediate water beneath the northern intermediate water.

The distribution of the depth and the value of the maximum salinity $S_{max.}$: In the subsurface tropical water mass (Fig. 5) indicates obviously in the deepest layer (100–200 m. depth). $S_{max.}$ lies in the regions of the North Equatorial Current (latitudes 20°–10°N.) and in the Kuroshio area. It lies in the shallowest layer (0–100 m. depth) in the western part of the North Pacific Saline Water (Salinity more than 35 $^{0}/_{00}$), having its axis along the line of Subtropical Convergence (water temperature in the upper layer above the 100 m. depth increases suddenly in the south over this Convergence).

In the Equatorial Counter Current area the depth of $S_{max.}$ again rises to its shallowest (depth almost less than 100 m.) above the optimum angling depth of tuna with the salinity of about 34.8 $^{0}/_{00}$ or less, which corresponds to the belt of the cold water (water temperature less than those in the surrounding north and south).

Beyond it to the south (latitudes 3°N.–3°S.), again the $S_{max.}$ layer sinks beneath 100–200 m. depth with the high salinity of 35.0–35.7 $^{0}/_{00}$, which corresponds to the water of the South Equatorial Current.

The distribution of surface salinity in winter and summer during the period 1931–35 (Fig. 6) shows the expansion of the North Pacific Central Saline Water mass in winter, lying in the zone of lat. 20°–30°N. around the axis of 22°–26°N., 165°–180°E., and the shrinkage in summer season in the period of 1931–35.

The water mass of low surface salinity (34.0–34.3 $^{0}/_{00}$) lying in the zone of the Equatorial Counter Current (lat. 5°–12°N.) which corresponds to the Equatorial Calm or Equatorial Rainy zone, and also

to the belt of the cold water at the depth 100 m. appearing more remarkable in winter than in summer.

In the region south from the lat. 4°N. to 3°S. we meet again the saline water mass of the Central South Pacific (salinity 34.5–35.2 ‰).

The northern and southern boundary lines of the Equatorial Counter Current (Equatorial Counter Front) lie at about 12°N. and 4°N., corresponding to the theoretical results obtained by Dr. K. Yoshida and others (1953).

ILLUSTRATIONS

FIG. 1.—Principal Watermasses and the Fronts in the NW Pacific. Explanation of Notations: LC—Liman Current, NKC—North Korean Cold Current, JCC—Central Cold Current in the Japan Sea, EKC—East Korean Warm Current, TC—Tsushima Current, CCC—Continent Coastal Current, ConF—Continental Front, CF—Cold Front in the Japan Sea, WF—Warm Front in the Japan Sea, KC—Kuroshio Current, OC—Oyashio Current, ESC—East Saghalin Cold Current, OF—Oyashio Front, KF—Kuroshio Front, STC—Subtropical Convergence, NEC—North Equatorial Current, ECF_1, ECF_2—Equatorial Counter Front, SEC—South Equatorial Current, ECC—Equatorial Counter Current, CoF—Coastal Front.

FIG. 2.—$S_{min.}$ ($^0/_{00}$) and its Depth during 1931–1935. (Shaded area means the zone of Double $S_{min.}$).

FIG. 3.—$S_{min.}$ ($^0/_{00}$) and its Depth during 1935–1938. (Shaded area means the zone of Double $S_{min.}$).

FIG. 4.—$S_{min.}$ ($^0/_{00}$) and its Depth during 1938–1941. (Shaded area means the zone of Double $S_{min.}$).

FIG. 5.—$S_{max.}$ ($^0/_{00}$) and its Depth during 1931–1938.

FIG. 6.—$S_{om.}$ ($^0/_{00}$) in Winter (Real line) and in Summer (Dotted line) 1931–1935.

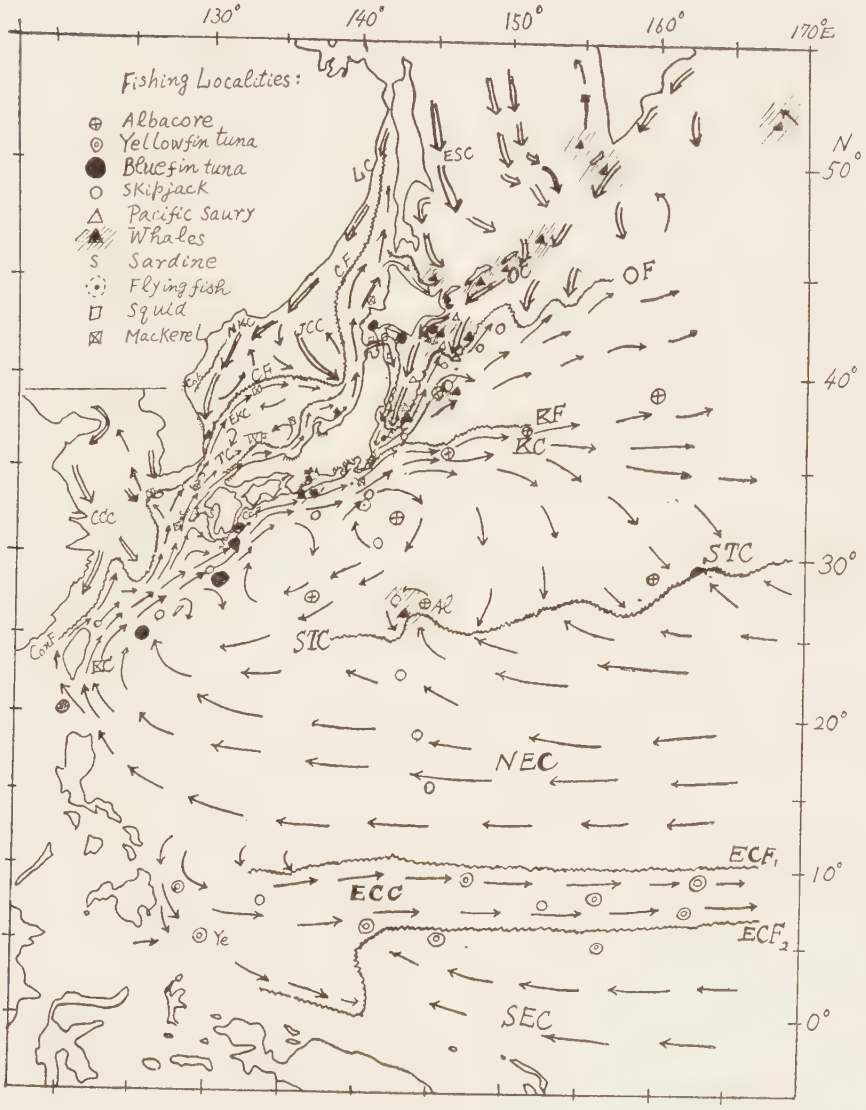
130°
140°
150°
160°
170°E
N.
50°
40°
30°
20°
10°
0°
Fishing Localities:
Albacore
Yellowfin tuna
Bluefin tuna
Skipjack
Pacific Saury
Whales
Sardine
Flying fish
Squid
Mackerel
ESC
LC
OF
KC
RF
CCC
STC
NEC
ECF1
ECC
ECF2
SEC
Ye
Al

FIGURE 1

200m
400m
600m
800m
1000m
340
341
342
343
344
345
346
180°
170°
160°
150°
140°
130°
120°
40°
30°
20°
10°
0°

FIGURE 2

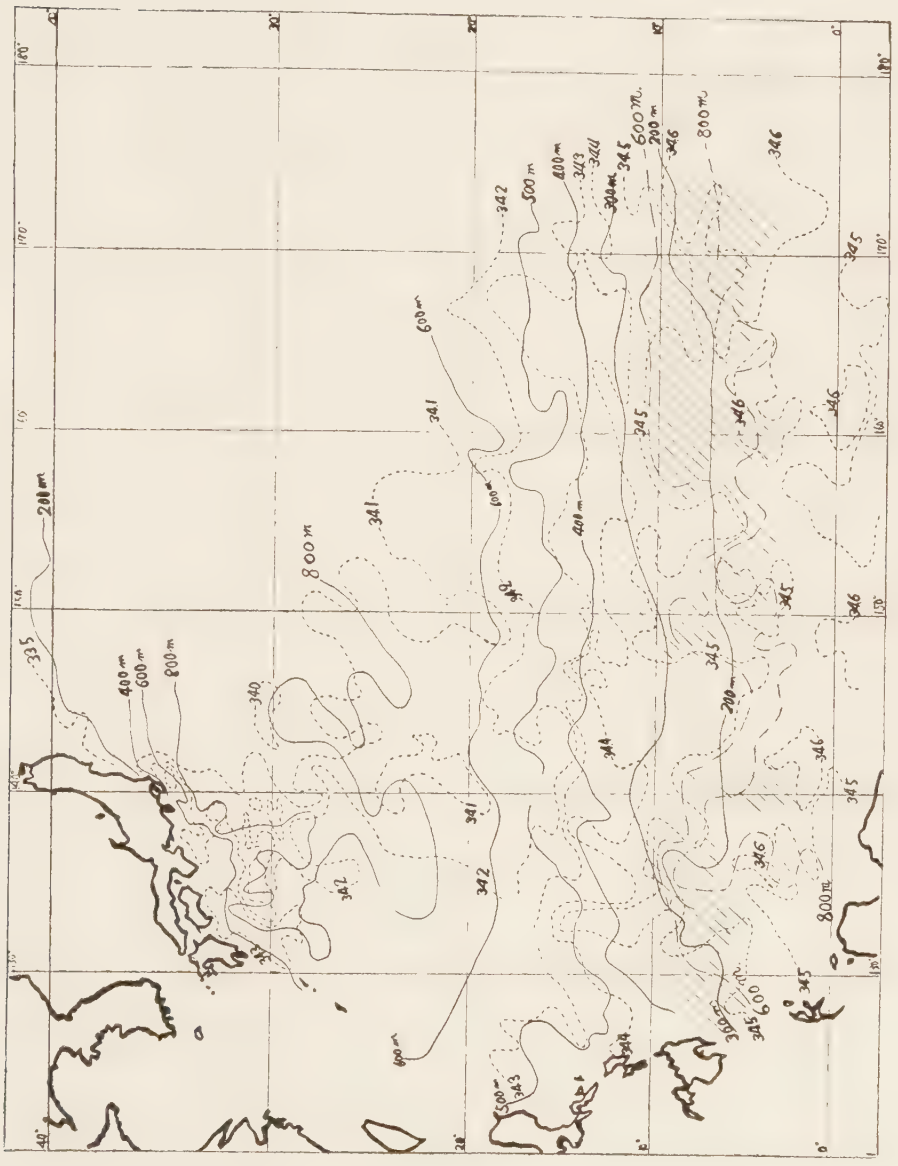

FIGURE 3

180°
170°
160°
150°
140°
130°
10°
20°
200 m.
400 m.
600 m.
800 m.
335
340
341
342
343
344
345
346
600m.
800m.

FIGURE 4

FIGURE 5

FIGURE 6

THE TOPOGRAPHY OF THE SEA SURFACE IN THE REGION OF THE PHILIPPINES

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Introduction

Under the Philippine Fishery Program the Fish and Wildlife Service conducted hydrographic surveys of all Philippine waters during the period 1947 to 1949. The *Spencer F. Baird*, one of the research vessels engaged in this program, made intensive observations of temperature, salinity, dissolved oxygen, and plant nutrients at the surface and subsurface levels during each of the two seasons characteristic of this area. Presented here are the charts showing the dynamic topography at the surface for each season.

Methods

Twenty-eight cruises (twenty of them hydrographic cruises) were made during the survey. Composite charts were drawn so that each chart combined data from all cruises in a particular season and year. The cruise numbers with dates are indicated on the charts. On chart 1 are presented the results of four cruises made during the period January to June 1949. This is during the season of the northeast monsoon when the winds are predominantly from the northeast. Chart 2 presents the results of three cruises taken from July to October, 1949. The two cruises taken during the period July to September are definitely during the southwest monsoon. The October cruise occurred during the beginning of the northeast monsoon of the winter of 1949–1950, but the current pattern at that time of year can be expected to represent that of the preceding season.

Discussion

The deduction of ocean currents from dynamic computations is beset with many uncertainties particularly in areas where the effect of internal waves are pronounced (Sverdrup, *et al.*, 1946, p. 453). In the present work no account has been taken of internal waves and the usual

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assumptions of no acceleration and no frictional forces, of course, were accepted.

However, the general current pattern indicated by the dynamic computations in these studies is considered reasonably correct. In areas where surveys were repeated during the same season but in different years, very similar patterns were obtained. Indeed, the most prominent basic features were found throughout the year.

The Pacific Ocean. The surveys on the eastern side of the Philippines in the open Pacific extended almost 300 miles offshore. It was hoped, when the station pattern for these surveys was laid out, that sections could be obtained across the northward deflection of the North Equatorial Current as it impinges upon the Philippines. However, our charts of dynamic topography show very little of this water movement. Evidently the main northward deflection of the North Equatorial Current occurs farther offshore. In the chart for the northeast monsoon there is a wide area of practically no motion off the island of Samar. Only at the outermost stations is there any indication of the northward deflected Equatorial Current.

There is a very strong northward close inshore along the coast of northern Luzon, but this flow does not appear to be part of the deflected North Equatorial Current but rather is the western side of a good clockwise eddy. To the northeast of this eddy there is a strong flow with a northwest set which probably represents the edge of the deflected equatorial water as it sweeps toward the island of Formosa. Whether the great eddy east of northern Luzon is permanent or not cannot be determined by our investigations as the October survey in the Pacific did not extend this far north. This survey as far as it goes shows no general northward movement within 300 miles of the coast.

The southward deflected water of the North Equatorial Current flows much closer inshore than that of the northern branch of that current. Schott (1939) indicated a line of divergence between the two branches at about latitude 11° to 12° north at longitude 130° east. From this point the line of divergence turned northward to end at San Bernardino Strait between the islands of Luzon and Samar. In his charts this line of divergence is approximately the same during winter and summer.

Our calculated currents are in line with those of Schott. In the northeast monsoon survey the line of divergence at longitude 130° east is at latitude 12° north. South of this the water flows toward the island of Mindanao and turns sharply south. Part of this water hugs the coast of Mindanao and flows as a strong current into the Celebes Sea. However, all along the eastern edge of this current water is deflected back to join the Equatorial Counter Current. From latitude 8° north

to latitude 5° north (the southernmost observation) there is a strong development of eastward flowing water consisting the origin of the counter current. The observations indicate that there is a strong flow of water northward from the region of Halmahera and that this turns eastward as the counter current in the area of observation.

According to Schott there is an extreme seasonal change in the water movements north of New Guinea with southeastward set in the northern winter and a northwestward set in the northern summer. One would deduce from his charts that the Counter Current is composed of quite different water in different seasons of the year. During the northern winter the eastward flow is composed largely of water which has been deflected from the North Equatorial Current, while during the northern summer it is composed largely of water which is carried northwestward from New Guinea and northeastward from the East Indies region. However, at the southeasternmost part of our area of observation, namely, at latitude 5° north and longitude 130° east, the direction of flow is always to the east. The Counter Equatorial Current is well developed at this point the year around even though the origin of the water may vary with the seasons.

Our observations during the southwest monsoon, which corresponds to the northern summer (Chart II), do not extend far enough south to reveal the fate of the southward deflected waters during that survey.

South China Sea. Surveys west of the Philippines covered the waters along the west coast of Palawan and to the north of this area off the coast of the island of Luzon. Along northern Luzon stations were occupied to a distance of 150 miles offshore. A line of stations extended across Luzon Strait to Taiwan (Formosa).

Two main features of the circulation in these areas seem to be maintained throughout the year. The first is a southwestward flow of water along the west coast of Palawan; the second is a large well developed eddy northwest of Luzon. In this huge eddy the water flows counter clockwise with movement to the north near the coast. The eddy was closer inshore in April than during the summer and the inshore current was much more highly developed in April.

Luzon Strait between northern Luzon and southern Taiwan (Formosa) is a region of swift and variable currents. It is in effect a region where the China Sea eddy to the west of Luzon borders the Pacific eddy to the east of Luzon. During April and May there was a strong flow of water through the Strait from the Pacific to the South China Sea in a northwestward direction (Chart I). During August there was a deflection of this water within the Strait itself. The strong flow of Pacific water into the China Sea in the southern half of the Strait was deflected

back into the Pacific in the northern half of the Strait joined by waters from the China Sea eddy.

Sulu Sea. During the investigations of Philippine waters four surveys of the Sulu Sea were made: two during the northeast monsoon and two during the southwest monsoon. The circulation patterns found during the first two surveys (one in each season) have already been reported (Graham, 1952). The present charts present the results of two more surveys, one in each season.

Comparing the results of the second northeast monsoon survey (Chart I) with those of the first northeast monsoon survey (Chart II; Graham, 1952), we find that the general current pattern is similar although apparently somewhat simpler. There is the same indication of westward flow from the Mindanao Sea. Within the Sulu Sea the general pattern is that of a large counter clockwise eddy. This eddy probably corresponds to the "South Central Eddy" found during the first survey of this Sea in October and December, 1947.

The currents indicated by the second southwest monsoon survey conducted in March and April 1949 (Chart II) also compare well with those found during the first survey made during the southwest monsoon made in June and July 1948 (Chart V, Graham, 1952). In 1948 the outstanding feature of the surface currents in the Sulu Sea was a flow of water from the South China Sea between Palawan and Borneo. This water flowed northeastward along the east coast of Palawan in a direction opposite to the flow characteristic of the northeast monsoon. The results of the 1949 survey (Chart II) show this same movement of water in that area of the Sulu Sea. In 1948 some of the water flowing in from the China Sea turned southward. This same movement was found in 1949 although more of it was deflected westward to form a small eddy. In 1949 the North Central Eddy dominated the central area of this Sea while in the 1948 survey both of the major eddies were well developed.

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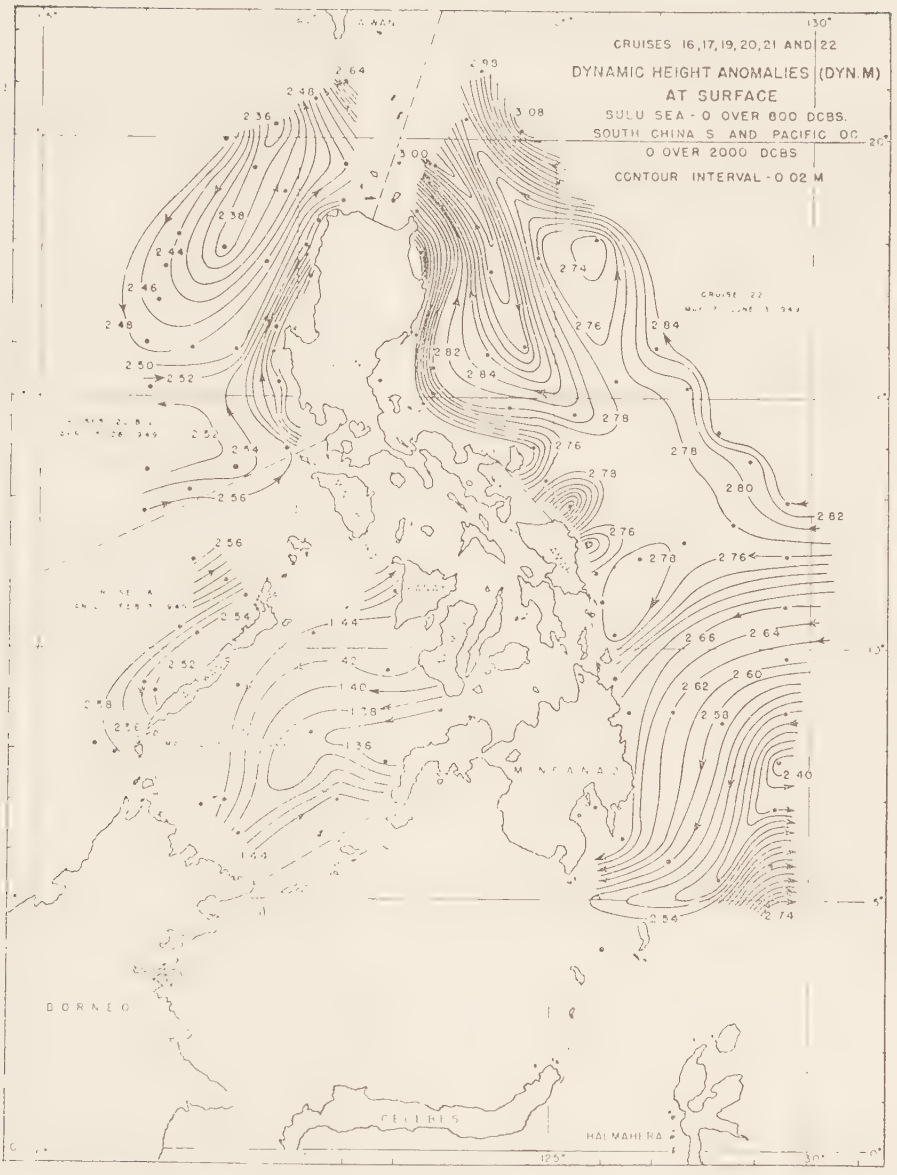

FIG. 1.—Surface topography during northeast monsoon.

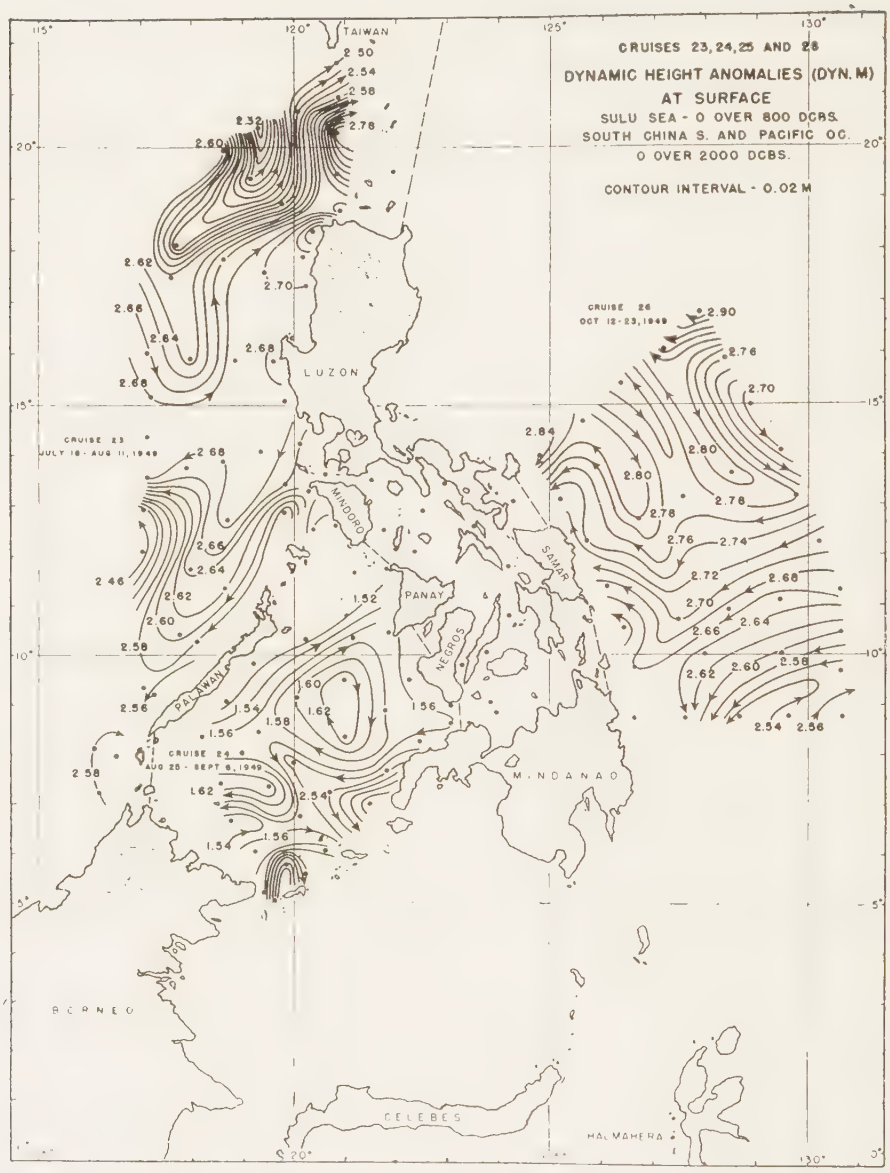

FIG. 2.—Surface topography during southwest monsoon.

RECENT OCEANOGRAPHIC EXPLORATION IN THE NORTH AND EQUATORIAL PACIFIC OCEAN

By Warren S. Wooster
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The exploration of the Pacific Ocean may be divided into three major phases. The first phase, that of geographical discovery, was initiated by Magellan and reached its climax in the voyages of James Cook. Early in the nineteenth century the general outline of the shores and the locations of most island groups of the Pacific had been fairly well established. Yet the early explorers were not oceanographers, and in their travels they discovered little about the sea.

The second phase of Pacific exploration and the science of deep-sea oceanography were both opened by the cruise of HMS CHALLENGER in 1873 to 1876. For the first time a major expedition was devoted to a study of the ocean itself, the physics and chemistry of its waters, the character of its bottom and the nature of its denizens. Expeditions in the great tradition of the CHALLENGER have continued up to the present day, notable among them being the cruises of the DANA and the CARNEGIE in 1929 and the recent voyages of the ALBATROSS and the GALATHEA. Such studies lead to a general description of the major characteristics of the Pacific Ocean from the physical, chemical, biological and geological points of view.

The third phase of exploration can be described as the detailed study of the spatial and temporal changes in conservative and non-conservative concentrations. The ocean is considered as a dynamic system, and the goal of this phase is the description and understanding of the processes bringing about changes in this system. Much work of this sort has been done already by scientists on both sides of the Pacific, using the classical tools of oceanography. The successful prosecution of this phase, however, requires eventually the development and application of new tools (such as the bathythermograph, geomagnetic electrokinetograph or high-speed plankton samplers) which can be used from a moving ship.

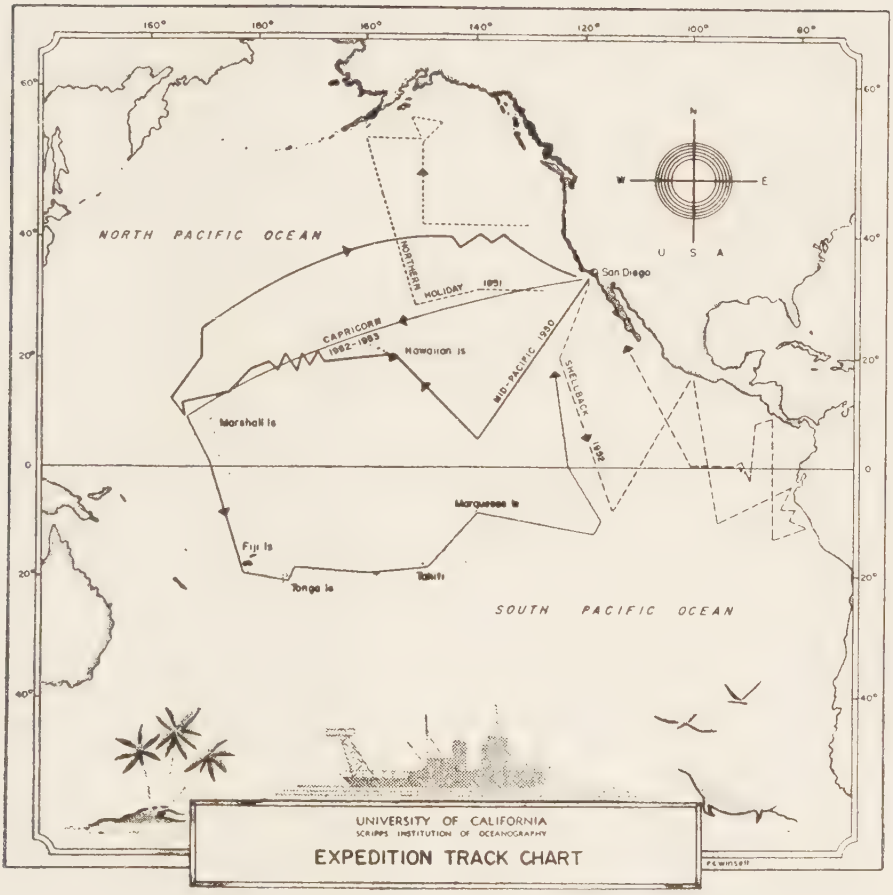
Although the five post-war expeditions of the Scripps Institution of Oceanography have made use of such new tools, their results belong properly to the second phase of exploration. The two expeditions in which the author did not participate differed in purpose from the others

and will be mentioned only briefly here. The MID-PACIFIC Expedition of 1950 in the eastern North Pacific, and the CAPRICORN Expedition of 1952–1953 in the Central Pacific were principally geological and geophysical in intent, studying the shape of the sea floor with the echo-sounder, the character and depth of bottom sediments with bottom samplers and by seismic refraction methods, and the transport of heat through the sea floor with the bottom temperature probe.

The NORTHERN HOLIDAY Expedition of 1951 in the eastern North Pacific, the SHELLBACK Expedition of 1952 in the eastern Equatorial Pacific, and the TRANS-PACIFIC Expedition of 1953 in the deep Bering Sea and the western and central North Pacific, were similar in basic purpose. In each case the course was laid out to cross the major current systems and to sample the principal water masses of the area. In each case the major work of the expedition was a series of hydrographic stations at 60- to 90- mile intervals where temperature and salinity were measured down to considerable depths, chemical analyses of water samples made, and quantitative plankton tows carried out. Between stations observations were made with the bathythermograph, geomagnetic electro-kinetograph, echo-sounder and midwater trawl. Geological and meteorological observations were also made on each expedition.

An effort was made to cross the major circulation features at approximate right angles to facilitate velocity and transport computations. By means of water mass and isentropic analysis it will be possible to map out the distribution of water types and to study their origin and subsequent transformation. In particular, the distribution of properties in deep water may cast some light on the little known intermediate and deep circulation of the Pacific. The distributions of dissolved oxygen, phosphate and silicate and of planktonic species are closely related to the distributions of conservative concentrations, and the results of these expeditions will make possible a careful study of this relationship.

In summary, the results of these five expeditions should contribute substantially to our knowledge of the major circulation and the distributions of properties and organisms in the Pacific Ocean. An understanding of time and space variations in this general picture must await the extension of phase three methods to deep-sea oceanography.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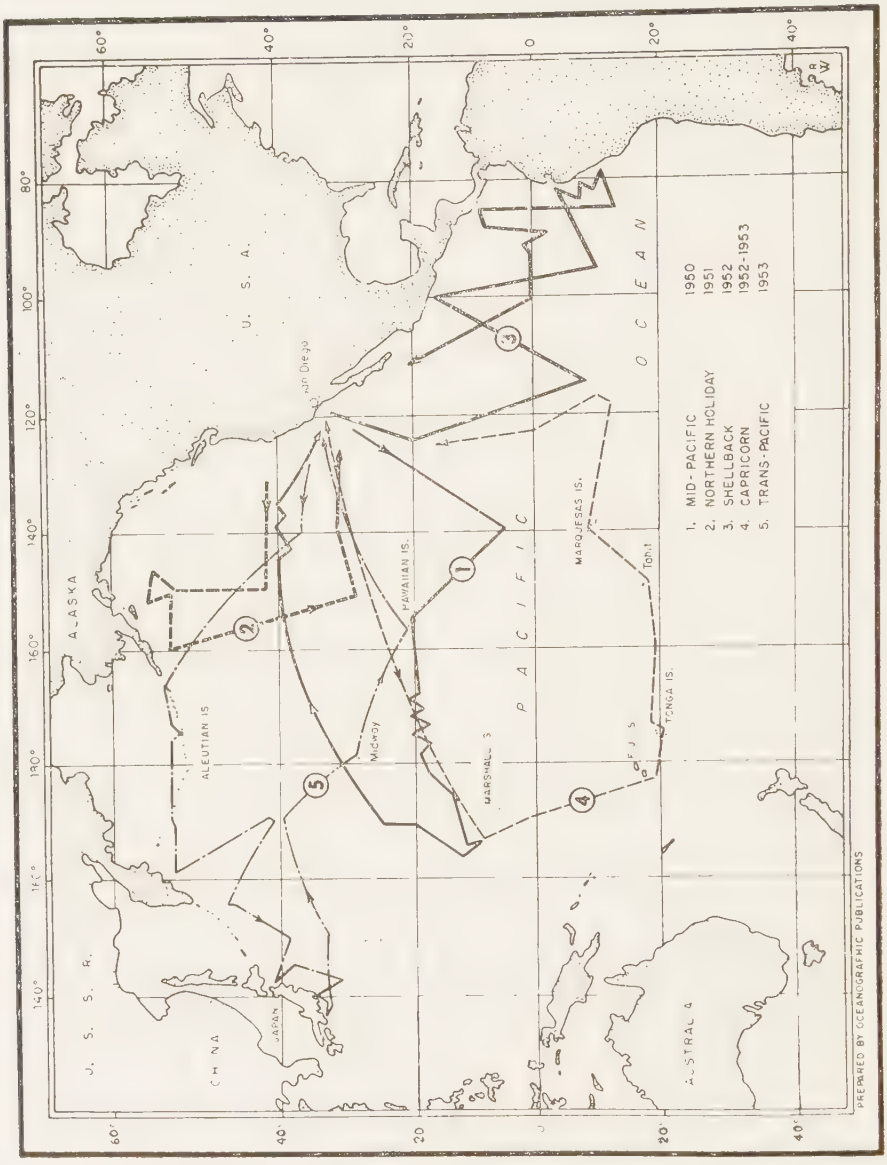
1. MID-PACIFIC 1950
2. NORTHERN HOLIDAY 1951
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4. CAPRICORN 1952-1953
5. TRANS-PACIFIC 1953
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ALASKA
U. S. S. R.
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TONGA IS.
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San Diego
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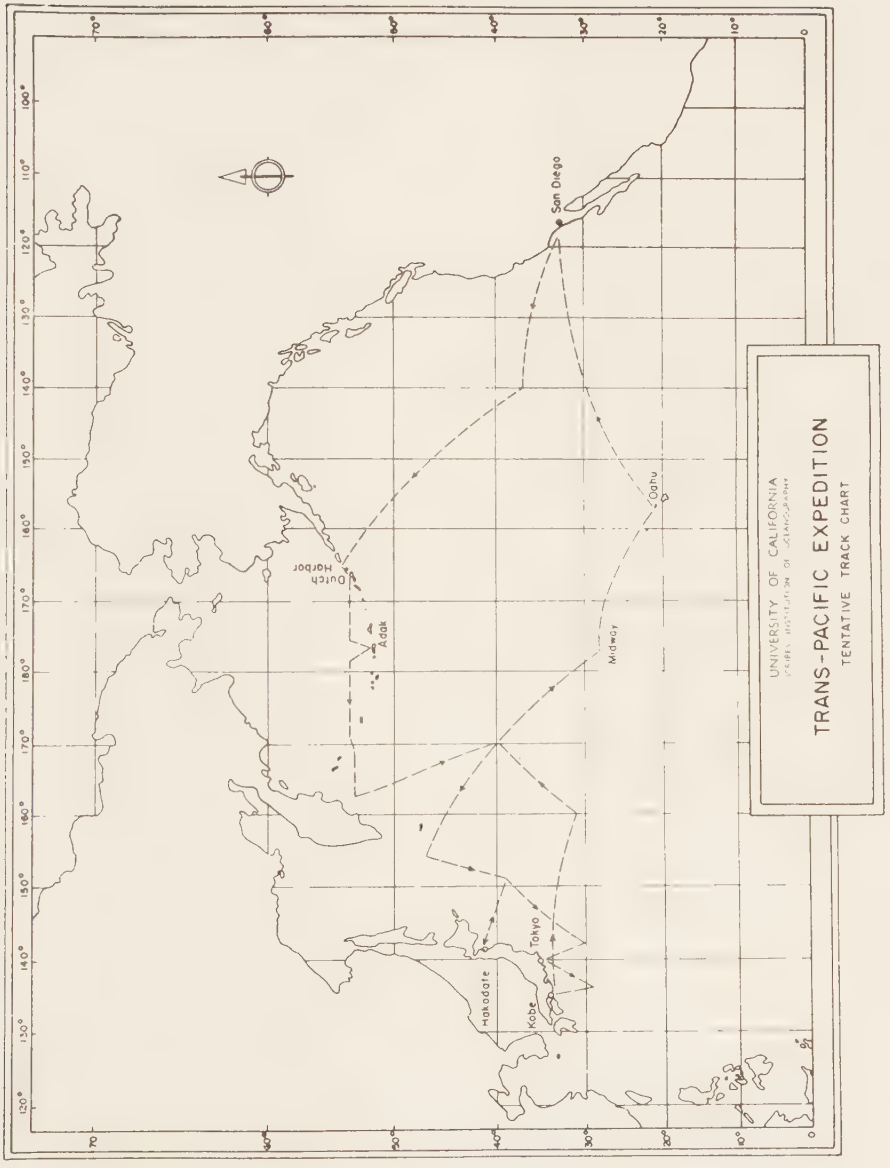
San Diego
Oahu
Midway
Dutch Harbor
Adak
Hakodate
Tokyo
Kobe
Guam
TRANS-PACIFIC EXPEDITION
TENTATIVE TRACK CHART
UNIVERSITY OF CALIFORNIA

BASIN WATERS OF SOUTHERN CALIFORNIA

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Abstract

Off the coast of southern California are 14 basins that are separated by submerged ridges. The sills of the basins are 475 to 1900 meters deep and from 150 to 880 meters above the basin floors. In general, the basins that are located farthest south have the deepest sills. Water below sill depth in the basins is isothermal at the same temperature that was found in the earliest measurements in 1931. It is also isohaline except for effects of diagenesis near the bottom. A close relationship between temperature and sill depth exists,—such that the northern basins with their shallow sills contain the warmest water. It is evident that the water in the basins comes from adjoining basins or from the open sea at a depth which is within 200 meters above to 40 meters below sill depth. This relationship makes possible the tracing of basin waters, which were found to flow northwesterly, in contrast to the general southeasterly moving surface currents.

AN OCEANOGRAPHIC MODEL OF PUGET SOUND *

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Introduction

Oceanographic observations must be made in great numbers and extend over long periods, in many cases years, in order to obtain a relatively complete understanding of the conditions existing in even a small estuary or bay. Resolution of the mass of data to provide the desired information is further complicated by the fact that none can be obtained under controlled conditions. Data obtained at different times are not directly comparable since the natural conditions neither remain constant nor precisely repeat. Thus a synoptic picture of the oceanography of an area may be considered only in general terms at best, and as the size of the area is increased the generalities must of necessity become broader.

In treating an area as large and complex as Puget Sound, the problems of obtaining a complete understanding of the over-all oceanography, under either normal or extreme conditions, from field observations alone are almost insurmountable. In recent years, hydraulic models of tidal estuaries have been used in increasing numbers as a guide in interpreting the conditions within the prototype. It is recognized that it is impossible to construct a reduced scale model rigorous of the prototype and that distortion and scale effects may easily lead to misinterpretation. Nevertheless, these small-scale models are useful in clarifying the nature of existing conditions and in planning more efficient field programs. Observations may be made under controlled conditions and, of utmost importance, a particular set of conditions may be set up in the model and repeated at will until all pertinent information is collected.

Description of the Area

Puget Sound (Fig. 1) branches to the south from the eastern terminus of the Strait of Juan de Fuca, between the Olympic and Cascade mountains of Washington. Its various arms, averaging less than 3 miles wide, have a total area of 767 square nautical miles at mean high water.

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The entire system lies within an area of about 40 by 90 nautical miles. It may be subdivided into four general sections which are partly isolated by vertical or lateral constrictions. The main basin extends from a 10-fathom threshold sill at the confluence of Admiralty Inlet with the Strait of Juan de Fuca, south to a 26-fathom sill at the Tacoma Narrows. The section south of the Narrows consists of a 100-fathom primary basin with many branching channels and inlets. Hood Canal, averaging about 2 miles wide and having a depth of 100 fathoms, extends about 50 miles southwest from Admiralty Inlet and is partly separated from it by a 30-fathom sill. The fourth section extends with diminishing depth from Possession Sound, about 25 miles from the entrance to Admiralty Inlet, north through Skagit Bay to Deception Pass. This pass is a very restricted channel about 150 yards wide and 10 fathoms in depth connecting with the Strait of Juan de Fuca. Puget Sound is relatively deep in comparison with other inshore waters of the United States with a maximum depth of 155 fathoms and with 50 per cent of its total volume lying below 25 fathoms.

The tides of Puget Sound are of the mixed type characterized by marked differences in the successive heights of low waters. Considerable changes in the tide with respect to character, range, and time occur within the area. Periodically, the tide near the mouth at Port Townsend loses its mixed characteristics and for several days each month becomes virtually diurnal. This effect does not extend into the system for any great distance and the tides are semidiurnal over the rest of the system at all times. The tidal range generally becomes progressively greater landward from the entrance. Port Townsend has a diurnal range of 8 feet while the inlets at the southern extremities have 15 feet. The rate of progression of the tidal wave into the Sound is altered by the topographic characteristics, particularly at the Tacoma Narrows, a narrow constriction between two of the larger basins, and changes with the character of the mixed tides.

The tidal currents also are subject to wide local variations and are dependent upon the tide range. The maximum velocities occur in constricted channels and may reach about 7 knots. The tidal prism in Puget Sound amounts to about 5 per cent of the volume below mean lower low water.

Numerous rivers and small streams feed into Puget Sound from a drainage basin of about 11,300 square miles within which precipitation varies locally from 20 to over 100 inches per year. The eleven largest rivers, having a combined mean yearly runoff of about 40,000 second-feet, account for about 80 per cent of the total fresh water influx, the Skagit alone contributing about one third. The peaking characteristics

of the rivers are governed by the major water sources. Lowland rivers peak during the winter from rainfall. Those rivers having mountainous areas as their principal watershed peak during the late spring from snow melt. Others may have both peaks. Hydroelectric developments on some rivers tend to flatten the peaks and maintain a more uniform runoff. Discharge varies greatly with flood stages being as much as 150 to 200 times the minimum flow.

The population of the area is over 1.5 million, the principal seaboard cities being Seattle, Tacoma, Bremerton, Port Townsend, Everett, Olympia, and Shelton. Virtually all sewage from the municipal systems is discharged untreated into the Sound. While industrialization of the area is not heavy, some industries, particularly those manufacturing pulp and paper, are potential pollution hazards because of the large volume and high oxygen demand of the wastes.

Construction of the Model

It is common practice to make tidal models as large as is consistent with space and facilities available and cost. The horizontal scale is ordinarily determined by these empirical factors. The vertical scale is governed by the practical requirements for suitable time scale and water depth in critical areas and by the theories of dynamic and kinematic similitude. Space available limited the present model to a horizontal scale of 1:40,000. The vertical scale selected was 1:1,152 or 1/16-inch per fathom, giving a distortion of 34.6:1. With these scales, the model is approximately 7 feet by 15 feet and has a maximum water depth of 10 inches with 1-½ to 2 inches over the critical sills. As a consequence of the distortion, some channels are deeper than they are wide. The time scale from the Froude modeling law is 1:1,178 or 3.05 seconds per hour, permitting a year's tides to be observed in 7.4 hours. With this choice of scales, the Reynold's number in the model will be in the turbulent region over the critical sills, for most of the tidal cycle. That the motion is actually turbulent is easily verified by inserting dye into the model and watching its rapid diffusion. The appropriate criterion for turbulence in a fluid with stable stratification is given by the Richardson number $\frac{g\, d\rho/dz}{\rho\,(du/dz)^2}$. With Froude modeling, the salinity scale must be unity to give the same Richardson number in model and prototype. With a reduced salinity scale, the mixing in the model could be expected to be increased.

The customary method of constructing model basins consists of moulding the contours to conform to templates fixed in position within the model area. This technique was found unsatisfactory for reproduc-

ing the fine detailing of contours required by the small scale and the complex system of narrow deep channels. A method was developed for casting the model basin in concrete from accurately-contoured hand-carved wood patterns. The contours used, established from the Hydrographic Charts of the area, were the elevations of mean high water, 75 feet, and 150 feet, and successive ten-fathom depth intervals below mean lower low water. The area was divided into 25 sections for convenience in preparing the patterns. The contours of each were transferred to white pine lumber planed to the thickness of the contour interval. The sections were then cut along the contour line and laminated in exact position. Excess wood was removed and the patterns brought to precise shape by careful hand-carving and sanding with constant reference to the charts for soundings between the contour intervals. Small basins were provided upstream from the river mouth for introduction of the river discharge. The wood was brought to a very smooth surface, sealed and varnished (Fig. 2).

The individual patterns were assembled in an inverted position upon a strongly supported platform 8 by 20 feet, constructed as a base for the model (Fig. 3). Forms were built around the assembled patterns with sheet metal separators between the pattern sections to form easily handled blocks. Copper tubing was placed from the outside of the forms to the river basins to carry the fresh water. The patterns were oiled to prevent sticking to the concrete. When the steel reinforcing was placed, a coating of smooth cement grouting was applied to the patterns. The forms were then filled to a uniform depth of 15 inches with a standard quick-setting concrete. Twenty-four hours after the concrete was poured, the forms were removed, and the blocks separated and inverted. The patterns were sprung out of the concrete by a method analogous to removing a tightly fitting stopper from a bottle.

The blocks were reassembled to form the model basin. A bitumastic compound was used to seal the joints between blocks. Surveying methods, combined with a latitude-longitude grid on the platform afforded accurate positioning of the patterns and of the completed sections. The method used insured precise fitting together of the blocks. The joints between the blocks and the minor defects which occurred during the casting were smoothed with plaster of Paris. The basin was finished with several coats of a vinyl resin paint (Fig. 4).

Tide-Generating Machine

The requirements for the tide-generating machine were that it closely reproduce natural tides and that it be adaptable to any model of regional waters that might be constructed at these Laboratories. It

was desired further that simple repeating tides could be set up and that a sequence of natural tides could be conveniently interrupted and repeated.

The tidal harmonic constants computed by the U.S. Coast and Geodetic Survey for Seattle and Port Townsend indicated that a minimum of six constituents would be required to reproduce prototype tides within a deviation of ±1 foot. These, the diurnal K_1, O_1, and P_1, and the semidiurnal M_2, N_2, and S_2, were incorporated in the tide-generating machine using many principles of the Coast Survey's prediction machine. Identical gear ratios were used for corresponding constituents. A 1/3-horsepower motor was used to drive a line shaft through a 900: 1 reduction box and spur gears at precisely one revolution in 12 solar hours, model time. Scotch yokes, driven from the line shaft by gear trains at speeds corresponding to the period of each constituent, generate cosine functions. These are fed into a summation wire connected through a suitable pulley and reduction drum arrangement (Fig. 5) to a plunger located in the model headbox. The changing water displacement caused by the motion of the plunger, shaped to correct for the tidal prism, produces the rise and fall of the tides. Phase angles and amplitudes for any epoch or location are readily set for the different constituents on the calibrated cranks of the Scotch yokes. A supplementary chain drive is incorporated between the M_2 and K_1 constituents to provide a means of generating repeating tides of either diurnal, semidiurnal or mixed character.

River System and Salt Water Addition

Provision is made for the introduction of fresh water through eleven major rivers of the area having a yearly mean discharge ranging from approximately 400 to 16,000 second-feet. The water flows by gravity from a constant head tank, through individual flow meters of the expanding bed type, to small basins located a short distance upstream from the river mouths. The rate of flow of the rivers is controlled manually by means of individual needle valves. Loss of salt resulting from river runoff is balanced by a circulation system in the headbox. Water is removed from the headbox through a shaped standpipe and pumped into a reservoir having a capacity of about 125 liters. Salt solution is added to the water in the reservoir to maintain the desired density. A second pump returns the water from the reservoir to the headbox where it is introduced along the bottom at a rate exactly balancing that of removal. In this way the net surface outflow from Puget Sound and the balancing inflow of oceanic water at depth is simulated.

Instrumentation

The design and development of instruments for measuring and recording tides, tidal currents, and the density structure in the model is complicated by the small scales and distortion. The sensing elements must be such that they do not significantly alter the properties being measured or interfere with the operation of the model. Further, because of the short time scale, it is necessary to obtain measurements rapidly in order to adequately differentiate conditions during the tidal cycle.

A portable recording tide gauge and an instrument for recording the salinity or density structure in the model have been designed and constructed. The recording tide gauge will resolve the model tides to within about 3 inches or 0.003 inch actual change in water level. The gauge is not affected by surface tension or factors other than change in the water level in the model. In principle it consists of an interconnected probe and recording arm operated by a synchronous motor. The probe alternately rises and lowers as the recording arm sweeps a stylus across electrosensitive paper being moved by a standard recording tape puller. As the probe, tipped by a fine platinum wire, contacts the surface of the water, an electrical circuit is completed which fires a thyrotron tube discharging a condenser. The charge from the condenser passes from the stylus through the paper to a second electrode consisting of a small roller extending across the underside of the paper. The discharge causes a small spark to burn a fine hole in the paper making a permanent black dot. The probe operates at a frequency of once per second.

The instrument for recording the salinity structure is based upon the conductivity of the water. The variations in the conductivity of a vertical section are electronically transposed to a plot of conductivity versus depth on an oscilloscope which may be photographed for a permanent record. The conductivity cell consists of a capillary 0.025 inch in diameter and 3/4-inch long, having electrodes at each end forming an integral part of the capillary. A maximum potential of about 50 volts at 10,000 cycles may be applied across the cell. Alternating current is used to reduce the effects of polarization of the electrodes. Water is drawn through the cell at a rate equivalent to the rate of displacement of water by the cell and tube to which it is attached, as it is lowered through the water. It has been found that measurements must be made while lowering the probe since some mixing and turbulence occur when the probe is raised, leading to fictitious values. Response is fast because of the rapid flushing of the cell.

Probing rate and depth of sampling may be adjusted as desired and operation is automatic. Camera operation is manual at present but may easily be adapted to automatic operation if desired.

Current Meter

Since the velocities and distances in the model are both very small compared to those in the prototype, it has proven impossible to use small-scale standard current measuring devices. The present method of current measurement consists of introducing small vortex rings of dye into the water at fixed time intervals and then to photograph their relative positions. This method has proved satisfactory and has the additional advantage of measuring both components of horizontal velocity simultaneously. The equipment consists of a glass capillary connected to a dye reservoir through a T section. A rubber bulb, connected to the other junction, is tapped at one second intervals by a hammer driven by a synchronous motor to emit a vortex of dye from the capillary tip.

Tide and Current Studies

A comparison of the tidal action in the model with that of the prototype was one of the first detailed studies undertaken as a part of the validation. The phase and amplitude changes between Port Townsend and key locations within the Sound were determined for each individual tidal constituent and compared with corresponding values for the prototype. Within the main basin, the time lag error was of the order of 6 minutes, or 0.3 second actual time greater than the Coast Survey values. Amplitude ratios agreed within 10 per cent. Beyond the constrictions of the Tacoma Narrows and those leading to Bremerton, the deviations were approximately double these values. A marigram of the six constituents for the first half of 1951 at Seattle was drawn by means of the tide machine using the Coast Survey tidal constants. The model tides at Seattle for the same period, generated by the tide machine adjusted to produce the correct tides at Port Townsend, were recorded. Portions of the recorded tides were compared with corresponding portions of the prepared marigram and with the tide table predictions (Fig. 6). The average deviation of the recorded tidal heights from the marigram was less than ± 0.5 foot. Measurement of the deviation in time lag was not obtained.

Quantitative measurement of the tidal currents and patterns of circulation have not been completed. Visual observations indicate that the model is giving good representation of prototype circulation, current patterns, and velocities, and the eddy patterns appear to follow quite well.

Density Structure

In the past, most tidal model studies have been concerned with silting in an estuary or harbor rather than the processes involved in and resulting from a variable density structure. Little work on the dynamics of an inhomogeneous system resulting from the interchange of oceanic water and river discharge in tidal models has been reported in the literature, and the theoretical requirements for similitude in this respect are not well resolved. It is thus necessary to determine the effects and interrelationships of the variable parameters in a model before representation of the prototype may be achieved. A series of studies was initiated to investigate the density structure as it is one of the major factors influencing the oceanography of Puget Sound. When the model structure under various conditions is known, it can be correlated with nature to establish any major differences and demonstrate possible corrective measures. For the purpose of this work, the salinity structure in each of the four main sections of Puget Sound was typified by measurements at Point Jefferson, Camano Head, Green Point, and Hood Point, (Fig. 7), under controlled conditions of tide, river runoff, and source salinity. (Repeating tides with an average range and diurnal inequality were used throughout this series of studies.)

In the first experiment, the equilibrium situation was obtained for mean river flow with a source salinity of $16^{0}/_{00}$, which, for the purpose of simplifying comparisons, has been related to a prototype salinity of $32^{0}/_{00}$. The results (Fig. 8) in general show a fresher surface layer with sharp gradients to a depth of 10–30 meters, below which there is a practically homogeneous more saline layer extending to the bottom. At first, it might appear that the homogeneous bottom layers were due to a lack of mixing of fresh water down from the surface; but that this is not the case is shown when the salinity of this bottom water is compared with that of the source water. At Point Jefferson and Camano Head, the bottom salinity is about $1^{0}/_{00}$ less than the source, while for Green Point the difference is about $1.5^{0}/_{00}$, which compares favorably with the differences obtained in nature. It must be that the mixing in these lower layers is sufficient to destroy any initial gradient.

The influence of the fresh water runoff on the salinity structure is best seen from the results of raising the flow of the Skagit River to the normal flood discharge rate of 50,000 c.f.s. (Fig. 8). After 1,000 consecutive days of flood, the effect of fresh water was noticed only to a depth of 80 meters at Point Jefferson although the surface layer had definitely freshened and deepened. At Camano Head, on the other hand, the deep water had freshened somewhat with no perceptible change in

the surface layers. Since the mechanism of these changes is not immediately clear, it will be a subject for further investigation. Off Green Point, the whole water column was freshened as would be expected since strong mixing occurs in that region and its water source is mainly the surface layers of the main basin. Thus even under these extremely extended conditions of flood, a noticeable gradient can not be maintained beneath the surface layers and another mechanism must be found to simulate the gradients which occur in nature.

Since in nature the source water of the Strait of Juan de Fuca does not hold a constant salinity throughout the year, the effects of a change in source salinity was investigated in the model. In order to make results clear-cut, a sudden decrease of salinity of $10^0/_{00}$ was maintained for 166 days and then increased back to its original value.

The decrease in source salinity (Fig. 9) was first noticed at Point Jefferson. A uniform gradient to a depth of 100 meters developed within 45 days. Subsequent mixing of these waters produced a homogeneous salinity to this depth with a sharp interface separating it from the more saline bottom water by 101 days. Mixing then gradually lowered the interface. The changes in salinity below 100 meters were minor during the first 101 days. As would be expected from the proximity and lack of sill between Camano Head and Point Jefferson, the sequence of events was very similar for the two stations. At Green Point, the salinity decrease was later at the surface, but when it did occur it was felt almost to the very bottom. After 166 days, the salinity was homogeneous in the bottom layer. At Hood Point, the fresher water was only noticed to a depth of 50 meters after 45 days, and only to about 70 meters after 166 days with very little change in the salinity of the bottom waters. Correspondingly, in nature the bottom water in Hood Canal has a tendency to stagnate.

An increase in source salinity produces a series of density gradients markedly different than above in both shape and rate of change (Fig. 10). Within 24 days, there was a considerable increase in salinity of the bottom water at Point Jefferson with the appearance of an almost constant gradient between the depths of 30 and 150 meters. After 38 days, the surface gradient was increased to a depth of 50 meters and decreased below that depth. This pattern continued until equilibrium conditions were reached after 89 days. At Camano Head, the salinity structure went through the same sequence although the mixing appeared to be faster between 20 and 70 meters. At Green Point, the increase in salinity was not great for the first 24 days, but thereafter there was a marked increase of salinity at all levels but never with appreciable gradients below the surface layer. At Hood Point, the heavier

water appeared to flow into a bottom layer below 100 meters before there was any effect above that level. After 38 days, however, there was more saline water at all layers with a relatively uniform gradient existing between 10 and 80 meters. At this time, the salinity below 100 meters had practically attained its maximum value. Equilibrium conditions were closely approached by the end of 89 days.

It is seen from these results that, with the exception of Green Point, significant salinity gradients will appear at all depths for appreciable lengths of time following a change in source salinity; whereas a change in river runoff will only have a minor and local effect. Qualitatively, these results are borne out in the prototype. Characteristically, the Puget Sound basins flush most rapidly in the fall when the Strait of Juan de Fuca water, the salinity source, is of its greatest annual density, and not during periods of maximum local runoff.

Model Applications

The model has been operated for groups of engineers interested in sewage disposal and pollution studies with good success. The insertion of dye at present or proposed sewage outfalls gives a clear and rapid picture of the pollution likely to occur at various localities. The value of a tidal model for this type of study may readily be appreciated when the ease with which a particular mass or type of water may be "tagged" by a suitable dye is seen. The transport and rate of dispersion of the water mass may be observed directly and continuously followed over large areas for the equivalent of long periods in the prototype.

The model has proven useful support of a fisheries-biology study concerned with the drift of fish eggs. The drift of dye in the model correlated with field observations clarified the movement of the eggs, location of the hatching areas, and distribution of the larvae. Continuous observations were made for a period representing many days in the prototype. Thus a detailed picture could be obtained from field observations which were somewhat scattered with respect to both location and time.

In planning field work, the model can be set to operate for the anticipated period of the cruise. The probable water structure and movement can be observed, and locations selected for most efficiently collecting the desired information. In an area of mixed tides, a tidal model which can be set to duplicate tides for a specific calendar period is a distinct advantage.

The model has proven to be a valuable teaching aid. The processes occurring in nature over a large area are readily observable, and a clear synoptic picture of their interrelations is thus obtained. Examples

of various features of inshore circulation can be pointed out and explained simply and easily. The student can use the model to obtain data corresponding to field measurements, and then work it up in the usual manner.

Summary and Conclusions

An hydraulic model of Puget Sound has been built and tested under various conditions. Equipment for controlling and measuring the oceanographic variables has been designed and put into satisfactory operation. Prototype tide and current are well represented by those in the model. It has been demonstrated that density structure similar to that in nature can be obtained by proper control of operating conditions, but no detailed comparison has been made between prototype and model structure under corresponding conditions.

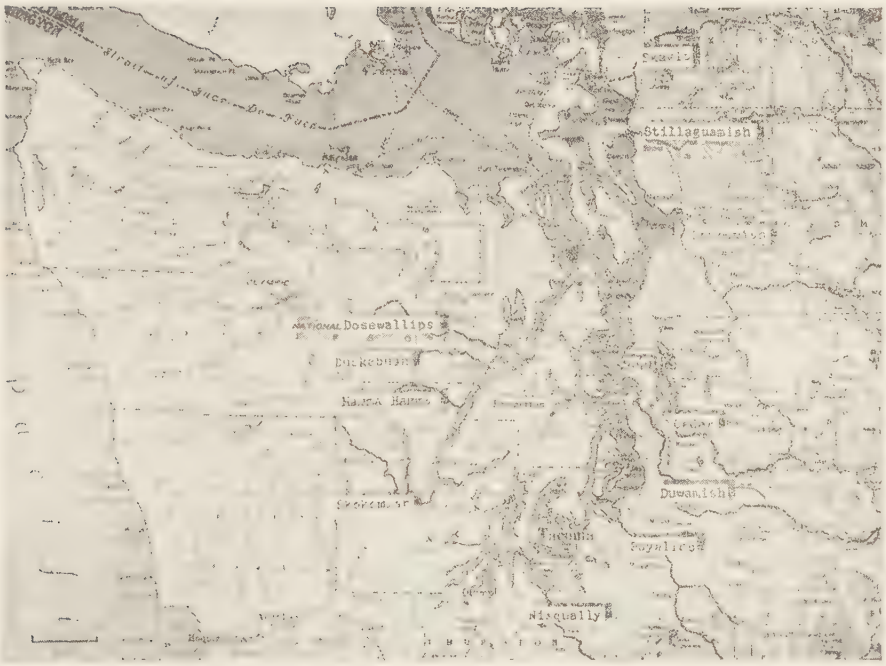

FIG. 1.—Puget Sound Area.

FIG. 2.—Wood pattern for casting section of basin.

FIG. 3.—Assembled patterns.

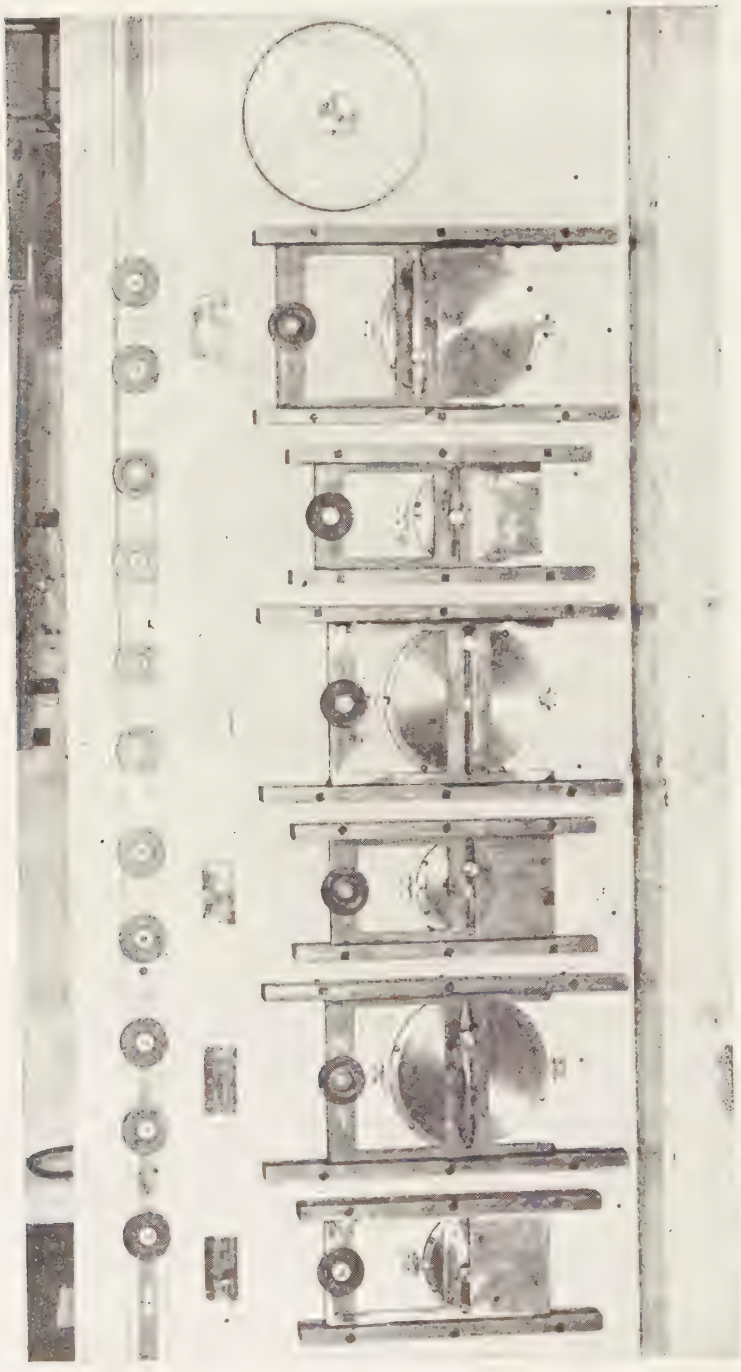

FIG. 5.—Tide machine panel showing Scotch yokes, summation wire and reduction drum.

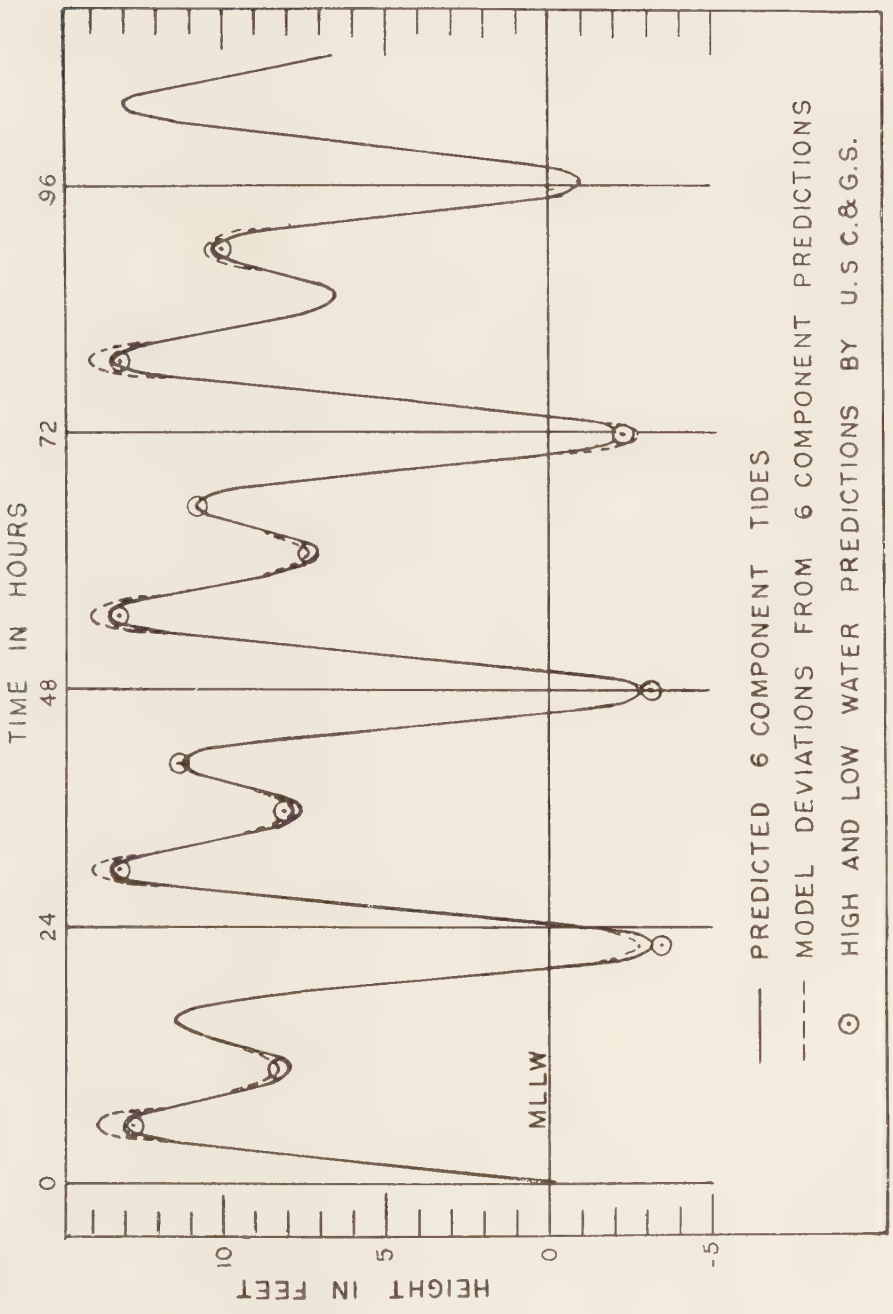

FIG. 6.—Comparison of Prototype and Model Tides of Puget Sound based on six components and corresponding heights of High and Low Water taken from the U.S.C. & G.S. Tide Tables.

FIG. 7.—Location of sampling stations for salinity study.

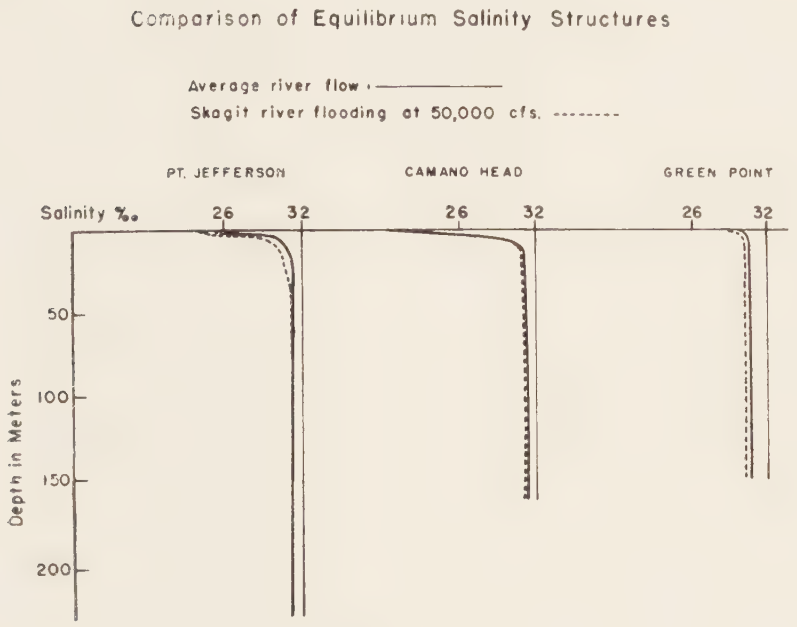

FIGURE 8

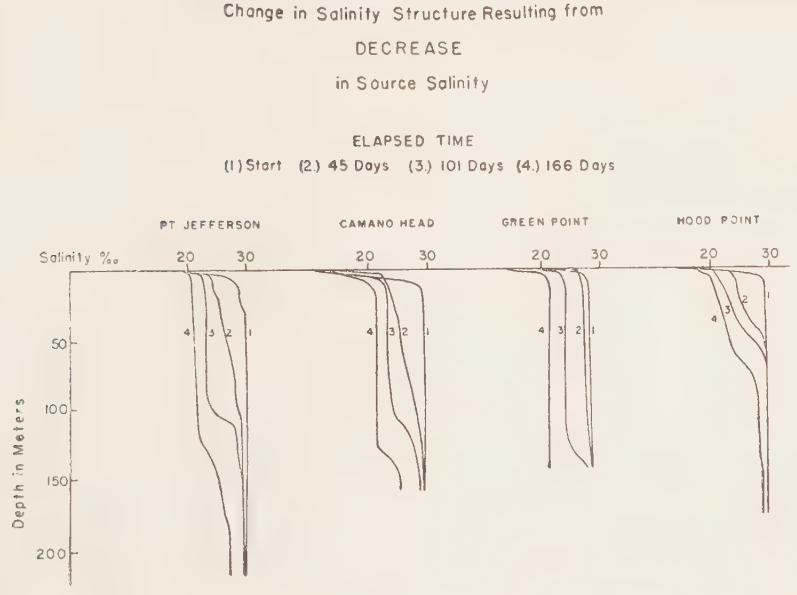

FIGURE 9

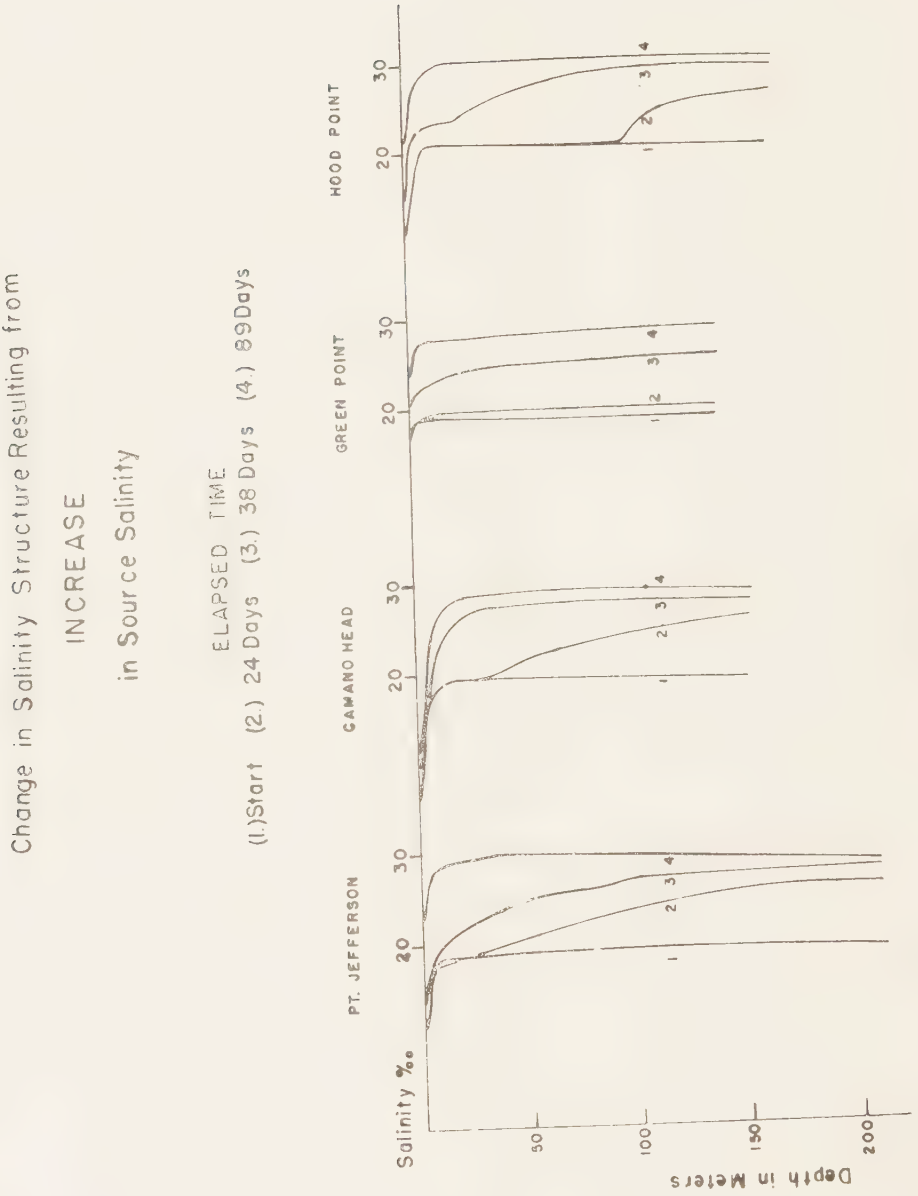
Change in Salinity Structure Resulting from
INCREASE
in Source Salinity
ELAPSED TIME
(1.)Start (2.) 24 Days (3.) 38 Days (4.) 89Days
PT. JEFFERSON
CAMANO HEAD
GREEN POINT
HOOD POINT
Salinity ‰
Depth in Meters
20
30
50
100
150
200
1
2
3
4

FIGURE 10

DAILY SEAWATER OBSERVATIONS ON THE PACIFIC COAST OF CANADA

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A programme of daily observations of surface seawater temperatures and salinities has been in progress on the Pacific Coast of Canada since 1933. Fourteen sampling stations are located at strategic positions (Fig. 1) along the extensive coastline so that each station monitors the conditions in a natural region. The majority of the stations are located at lighthouses (Fig. 2) where the lightkeeper carries out the duties of water sampling in addition to his regular duties.

The procedure and apparatus are quite simple. The observer takes the daily sample during the last hour of the rising tide occurring in the daytime. A two-ounce medicine bottle is inserted in clips attached to a wooden rod and lowered to a depth of three feet. The bottle is stoppered with a rubber cork on the end of a guided brass rod, and the sample is obtained by pulling out the stopper. Fastened alongside of the bottle clips is a brass protective case containing a mercury Fahrenheit thermometer. The whole apparatus is left immersed in the sea for two minutes, then the stopper is replaced in the bottle and the rod raised. The observer immediately reads the temperature and records it on a dated label already placed on the sample bottle, which he then seals with a wax-impregnated cork. Date, time of sampling and water temperature observed are also recorded on a data record sheet.

The bottles are packed in cases of one hundred, and are shipped to the central laboratory where the salinities are determined by a modified Mohr titration. The water temperatures and salinities are published in annual volumes entitled, "Observations of Seawater Temperature and Salinity on the Pacific Coast of Canada." These data provide a continuous record of the changes occurring in the marine climate of the waters surrounding each station, and provide a backlog of information which can be used to illustrate the year to year fluctuations in the overall coastal oceanographic conditions. These data might provide the only clue in determining why the fishery in a certain coastal region changed in volume from one year to the next.

Climate in the Sea

Seasons can be defined in the sea (Fig. 3) just as they are in the atmosphere. Summer is that period when water temperatures are at a maximum, which in the northern hemisphere occurs in the month of August. Winter is the season when they are at a minimum, usually December and January. Spring and autumn are the transition periods from these two extremes. The extremes and durations of these marine seasons differ from year to year due to changing atmospheric conditions. That is why these daily seawater records are so valuable. It is only by reference to these records that the scientist is able to measure just how great the annual variation has been. The daily seawater records will show these annual changes more clearly than meteorological data because they reflect the combined effect of the varying atmospheric factors of solar insolation, wind, rainfall, and land drainage.

Along such an extensive coastline as British Columbia, there are several different types of oceanic regions. The locations of the water sampling stations have been chosen so that the various types of regions are all being recorded by daily surface observations. The annual range of seawater temperature varies from station to station and this difference in annual temperature range is a criterion to the type of region being observed. For instance, in Figure 4, Langara shows an annual temperature range of 10°F, typical of an *exposed open ocean* region; Kains shows a slightly higher annual range of 11°F, typical of an *exposed coastal* region; Entrance shows a high annual range of 18°F, typical of a *protected coastal* region; and Race Rocks shows a low annual range of 6°F, typical of a region of *great turbulence*.

The annual salinity cycles observed at the various seawater sampling stations (Fig. 4) are typical of three climatic regions. Summer salinity maxima (Kains) are due to coastal upwelling and low summer precipitation with little subsequent fresh water runoff. The degree of coastal upwelling is governed chiefly by the force and duration of winds blowing offshore during the summer. In these latitudes, the winds are never in a continuous steady state, and assessment of the degree of upwelling from wind data alone would be quite difficult. Observation of the effect of these winds as indicated by the surface salinities is a much easier matter.

Fresh water runoff from the many large rivers that drain into the Canadian Pacific area is at a maximum in the summer because of the melting of snow at the sources of the rivers far inland. This effect is demonstrated by a summer salinity minimum at all the sampling stations situated near the mainland coast, such as Entrance Island. Here again, measurement of the combined effect of the various atmospheric

factors creating this summer freshet, such as solar insolation, previous winter snowfall, and wind, is easily monitored by the simple observation of the changes in seawater salinity.

The third type of marine climatic region is that where the annual salinity variation is very slight. On the Canadian Pacific Coast, this can be further divided into two sub-classes, one where the station is exposed to the deep open ocean (Langara) and the other where the station is located in a turbulent water-way (Race Rocks). There is very little annual salinity variation at Langara, but the records will demonstrate the year to year changes caused by major alterations in the system of offshore circulation (Figs. 6 and 7). To measure these large scale circulation patterns is a major oceanographic undertaking, and is sometimes not possible owing to lack of facilities. But an idea of the extent of the change in unsurveyed periods can be estimated from surface seawater observations made at the exposed ocean stations.

The annual salinity changes observed in turbulent sea-ways serve to measure the extent of mixing of the more saline deep waters with the less saline surface waters. The Fraser River flows into Georgia Strait and is eventually discharged to the ocean past Race Rocks in the Juan de Fuca Strait. It may be noted that there is a slight drop in salinity at Race Rocks during the month of August, following a large decrease in salinity during June and July at Entrance Island, further north in the Strait of Georgia. Comparison of the records in these two stations which are subject to the influence of the one major river, shows the difference of the degree of this influence in adjacent and connecting regions.

Combining both water temperatures and salinity records, it is possible to measure the annual seasonal fluctuations in the oceanic climate. This is a simpler method than trying to evaluate the more variable atmospheric phenomena from meteorological records and applying their effects on the oceanic state.

Monitoring Oceanographic Conditions

The oceanographer determines the changes that occur in the sea from year to year and from season to season by conducting detailed examinations of the various properties of sea water, chiefly the temperature and salinity. On the Pacific Coast of Canada there are several general types of oceanic regions, each demonstrating a typical pattern of seasonal variation in the properties of temperature and salinity. This pattern is similar from year to year, but the extent and duration of the change from one season to another varies. The seawater sampling stations have been located in such a way that they sample the ocean waters

of these typical regions. Once the oceanographic conditions of an area have been determined for each season of the year by means of oceanographic surveys, it is only necessary to refer to the daily seawater records to recognize annual changes in the properties of the water. Thus, Langara and Cape St. James record the *exposed open ocean* regions; Triple, Sandspit, Ivory, Entrance, Texada, Departure Bay and East Point record the *protected coastal* regions; Kains and Amphitrite record the *exposed coastal* regions; and Pine, Cape Mudge and Race Rocks record the *turbulent sea-ways*. The Pacific coastline of Canada is so extensive that these typical oceanic regions occur in widely separated locations where the determining factors of meteorological conditions, fresh water runoff, and tide might be quite different in magnitude. This is especially true of the region of Georgia Strait, where the extensive variation in local geographic conditions creates several sub-classes of oceanic regions.

The oceanography of the Georgia Strait (Fig. 1) is dominated by the fresh water discharge from the Fraser River. This fresh water flows over the surface of the strait, mixing all the time with the underlying salt water as it flows in a northward direction along the eastern shores. Once these surface waters reach the vicinity of Cape Mudge they turn south and flow along the western shore and finally empty into the Juan de Fuca Strait (Figs. 5 and 6). The passage of this brackish upper zone of water can be marked by the changes in surface salinities at Entrance Island, Cape Mudge, East Point, and finally Race Rocks. The diluting effects of the Fraser River discharge and the degree of mixing with the deeper salt water can be measured by the salinity changes observed at Entrance Island (Fig. 7). A series of oceanographic surveys extended over a period of two years have determined the circulation patterns in Georgia Strait for every month of the year. It is now only necessary to refer to the annual changes in salinity at Entrance Island in order to predict the occurrence and duration of any of the seasonal patterns previously determined by the oceanographic surveys.

Another application of these daily seawater observations to observing oceanographic conditions is in the "offshore" area. During August of 1950 and 1951 oceanographic surveys were made of the northeast Pacific Ocean extending to 500 miles offshore. In 1950 (Fig. 8) there were three clouds of warm water (60°F) lying in a band parallel to the coast with colder water on either side. In 1951 (Fig. 9) the warm water covered the southwest part of the area surveyed. The surface water temperature increased steadily to seaward and decreased to the north. An examination of the August mean surface water temperatures observed at four seawater sampling stations located on the coast showed that the irregular 1950 "offshore" surface conditions were associated with an ir-

regular sequence of monthly mean temperatures at these stations for this year (Fig. 10). The more regular 1951 "offshore" conditions were associated with a regular decrease of monthly mean temperatures at these same stations from Amphitrite in the south to Langara in the north. Although the oceanographic surveys were conducted during the months of August and July, the sequence of coastal temperatures for each year showed the same pattern as that following in August; so it should be possible to predict changes in the oceanographic state of the "offshore" waters from an examination of the surface temperature trends exhibited by these daily seawater stations.

During the summer of 1950 there was an excellent tuna fishery off the Canadian Pacific Coast. In the following summer, 1951, very few tuna were caught in the same area. Tuna are a warm water fish and their occurrence in Canadian Pacific waters could be due to the warm water cloud circulation observed in the August 1950 oceanographic survey previously mentioned (Fig. 8). A correlation between the variable "offshore" temperature distribution of 1950 and 1951 and the seawater temperatures measured at coastal sampling stations has been postulated. The value of this correlation will be immeasurable if it can be extended to serve as a means of prediction of the availability of tuna to the fisheries in this marginal region.

Daily Seawater Observations Assist Fisheries Investigations

Fisheries biologists are finding significant correlations between changing ocean conditions and fluctuations in the availability of fish. These studies have only been instituted in recent years because of the inadequate catch statistics for previous years. The scope of these studies covers the effect of ocean environment on spawning populations, juvenile fish and adult migrations. It has been demonstrated that the daily seawater observations can be used to monitor the changes in the conditions of the sea in the several climatic regions on the Pacific Coast. It is now only a short step to the next logical phase of using these daily observations to assist in the prediction of fish availability.

Investigations have already been made into the possibilities of a correlation between the July sequence of coastal station temperatures and the offshore tuna fishery, with quite encouraging results. The tuna fishery for 1952 was as unsuccessful as that for 1951, and an examination of the July and August mean temperatures for the same four coastal stations showed a similar characteristic of a regularly decreasing temperature from south to north. It was not possible to make an offshore

oceanographic survey during the summer of 1952 to determine the temperature distribution pattern, so these daily records from the coastal sampling stations were doubly important because they are the only criteria of what type of surface temperature distribution must have existed in these offshore waters during the summer of 1952.

Considerable research has been done on the relationship of seawater conditions in Hecate Strait, as monitored by Triple Island station, and fluctuations in the strength of lemon-sole year classes in the fishery in that area. Researchers have found that when the water temperatures during January and February are lower than normal there is an increase in the availability of fish in April and May. Further studies are progressing to determine why the relationship exists.

An association has been found between availability of the cohoe salmon in the fishery off the west coast of Vancouver Island and the salinities of the coastal waters as observed at Amphitrite and Kains sampling stations. It appears that higher than normal inshore salinities during the summer months provide better cohoe fishing for the inshore boats and poor fishing for the offshore boats. Studies concerning the ocean environment of salmon and their feeding habits are being continued to determine the reason for this correlation.

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ILLUSTRATIONS

FIG. 1.—Chart showing the location of daily seawater stations on the Pacific Coast of Canada.

FIG. 2.—An aerial photo of Triple Island lightstation. (Photo courtesy R.C.A.F.)

FIG. 3.—Seasonal variations of the water and air temperatures at Kains Island, Quatsino Sound, for the year 1935.

FIG. 4.—Average seawater temperatures and salinities at four typical sampling stations for 15 years, 1934-1949.

FIG. 5.—Distribution of salinity at two yards depth in Georgia Strait, February 1950.

FIG. 6.—Distribution of salinity at two yards depth in Georgia Strait, June 1950.

FIG. 7.—Seasonal variation in Fraser River discharge and surface salinity at Entrance Island station, 1950.

FIG. 8.—Surface temperature distribution, north-east Pacific Ocean, August 1950.

FIG. 9.—Surface temperature distribution, north-east Pacific Ocean, August 1951.

FIG. 10.—The sequence of monthly average temperatures along the ocean coast of British Columbia.

Long. 128° W
132°
124°
DIXON ENTRANCE
Langara I.
Triple I.
Skeena R.
Location of Stations Making
Daily Seawater Observations
Stations are Underlined
e.g. Langara I.
54°
Sandspit
HECATE STRAIT
BRITISH
Ivory I.
Lat. 52° N
Cape St. James
QUEEN CHARLOTTE SOUND
COLUMBIA
Pine I.
Kains I.
50°
Cape Mudge
VANCOUVER ISLAND
PACIFIC OCEAN
Georgia Strait
Departure Bay
Entrance I.
Fraser R.
Amphitrite
East Point
Race Rocks
48°
U.S.A.

FIGURE 1

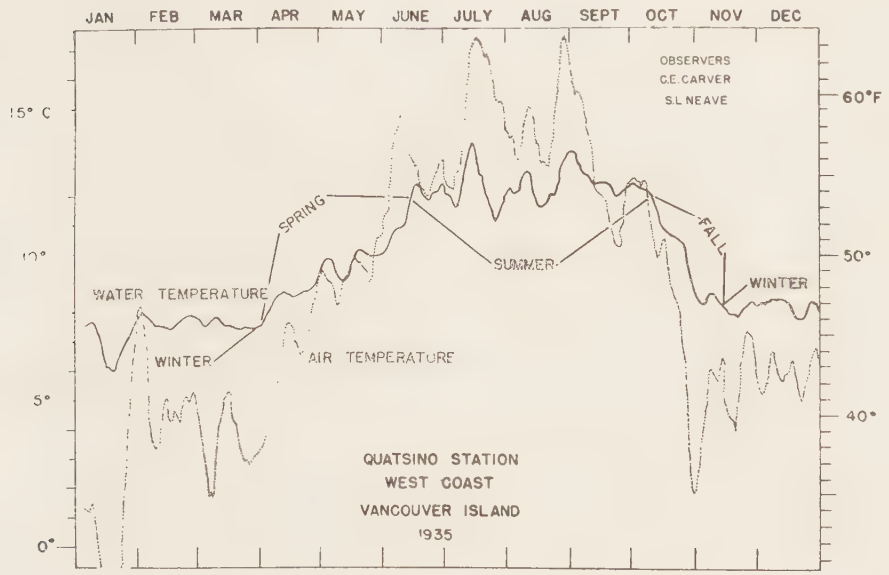

FIGURE 3

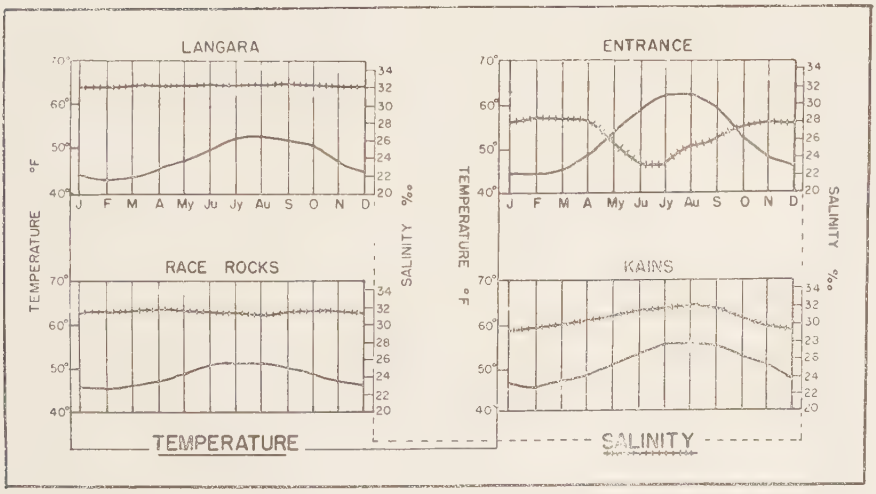

FIGURE 4

124°
123°
BRITISH COLUMBIA
VANCOUVER ISLAND
ENTRANCE ISLAND
VANCOUVER
FRASER RIVER
ACTIVE PASS
VICTORIA
JUAN DE FUCA STRAIT
49°
28
26
24
22
20
VERTICAL CROSS SECTION
A
B
30‰
DEPTH FEET
200
300
400
500
0 10 20
Sea Miles
Scale of Distance
125°

FIGURE 5

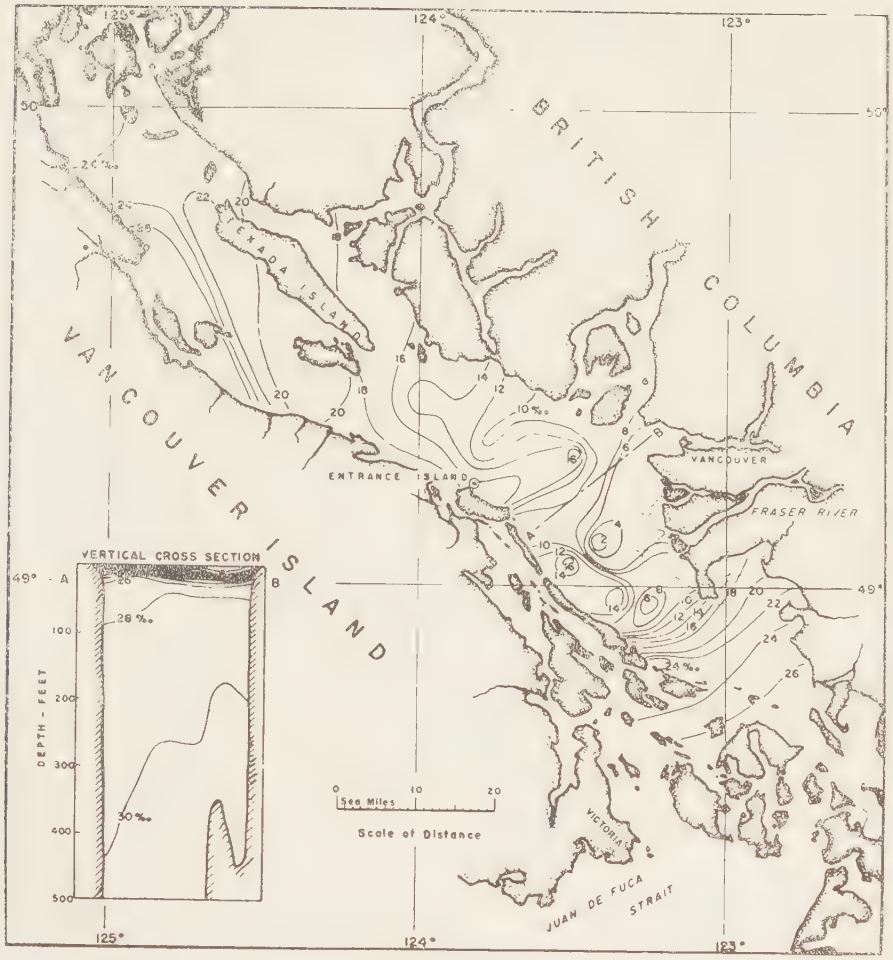
125°
124°
123°
50°
49°
BRITISH COLUMBIA
VANCOUVER ISLAND
QUADRA ISLAND
ENTRANCE ISLAND
VANCOUVER
FRASER RIVER
VICTORIA
JUAN DE FUCA STRAIT
VERTICAL CROSS SECTION
A
B
DEPTH - FEET
100
200
300
400
500
28 ‰
30 ‰
0 10 20
Sea Miles
Scale of Distance

FIGURE 6

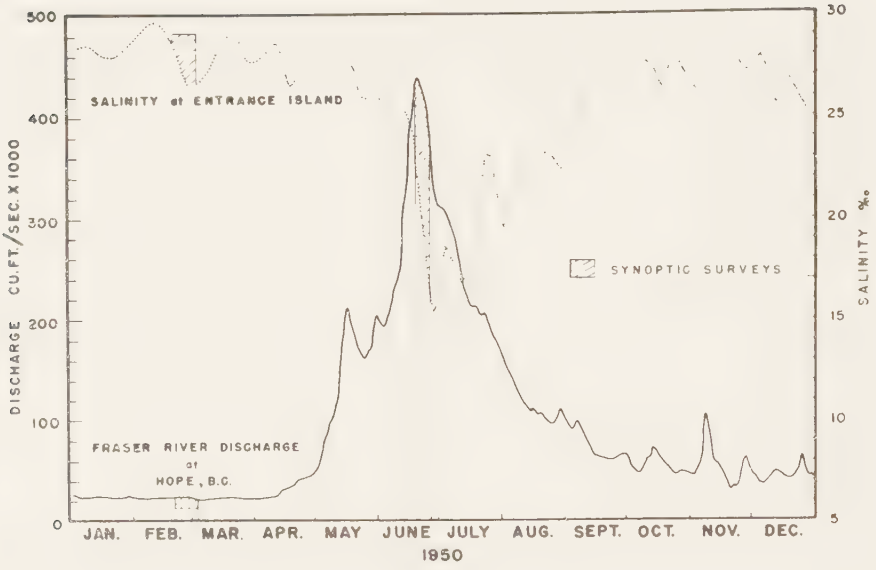

FIGURE 7

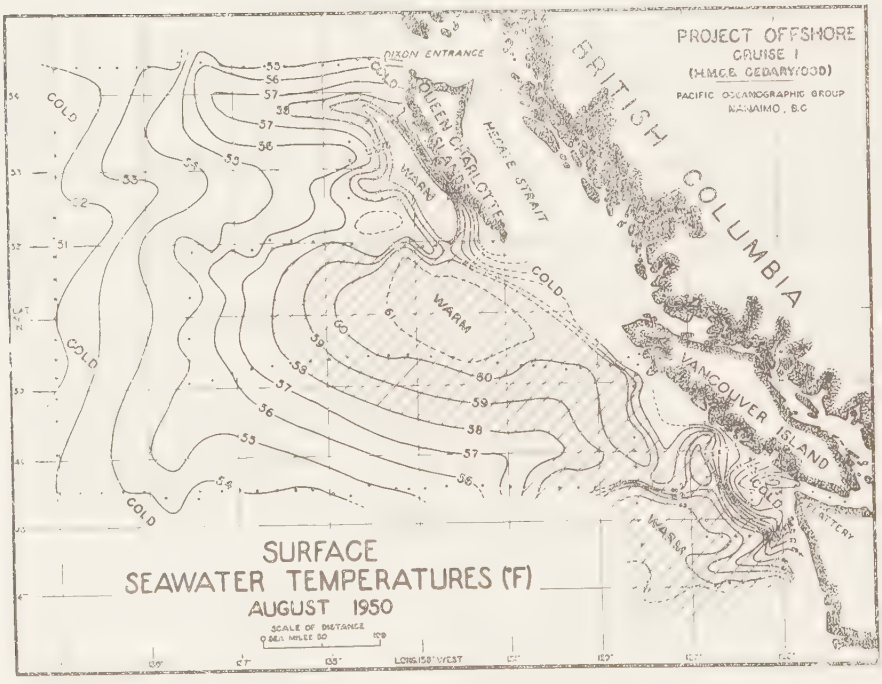

FIGURE 8

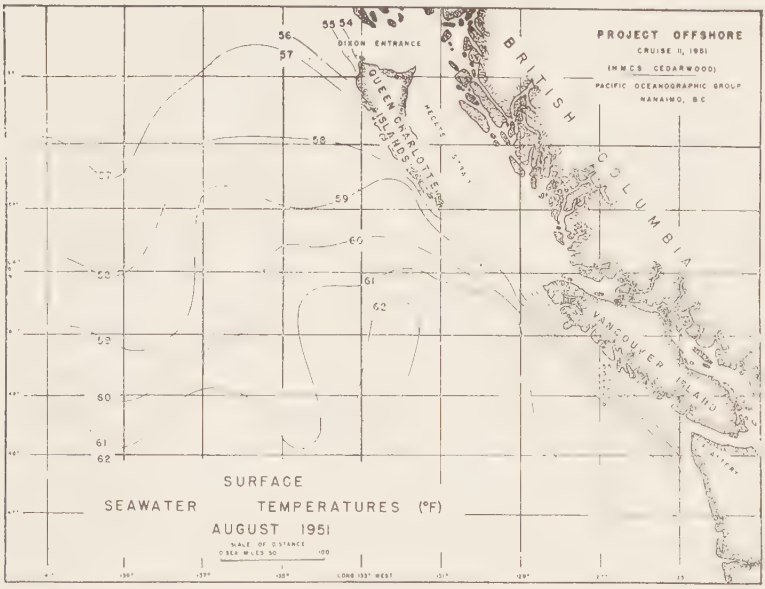

FIGURE 9

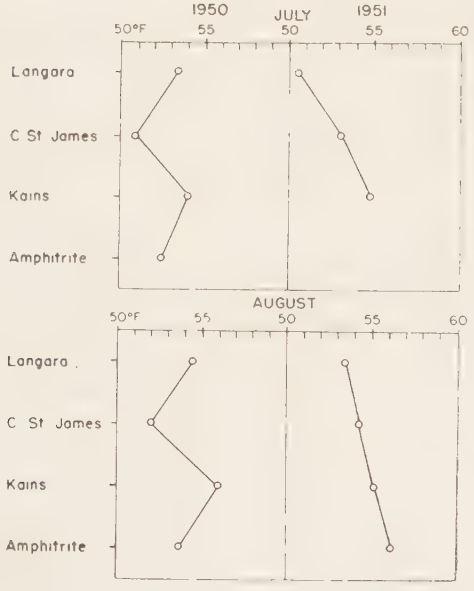

FIGURE 10

A STUDY OF LOCAL VARIABILITY IN MARINE SEDIMENTS *

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Introduction

The sampling problem involved in obtaining any natural sample is often exceedingly complex and has received much consideration in the literature. In the process of obtaining any one sediment sample by means of a coring tube or other sampling device, only an exceedingly minute portion of the sea bottom is sampled. In a strict sense any single sample is merely representative of the exact spot sampled. Unless the process of sampling continues systematically in this and adjacent areas, radial extrapolation from the sample is subject to great error, with any single sample being representative of only itself. The introduction of this limitation on problems of sedimentation or sedimentary environmental studies, whether they be physical, chemical, or biological, presents a serious handicap. In order to proceed with any sedimentary research it is necessary to know the limitations of the samples obtained and to understand, at least to some degree, the existing local variations and the probabilities for such variations.

The purpose of this paper is to briefly present some of the initial results concerning a problem of sampling marine sediments in the region of Puget Sound, in the State of Washington. The information to date consists of the data from a particle size analysis of the bottom sediments obtained along an east-west traverse of Puget Sound, about 12 miles north of the city of Seattle.

Regional Description

Puget Sound is a pre-existent valley system which has been partially drowned by the sea. It is one of the deepest salt water basins in the United States. The mid-channel bottom area exceeds 900 feet in depth in some localities. Depths of 600 or more feet below sea level are usually encountered in the channel portions of the Sound. Except for local areas, the shore slopes and underwater slopes are steep; inclines of 25 degrees are common.

* This work was supported by the Office of Naval Research under Contract No. N8onr-520/III, Project NR 083-012, with the Department of Oceanography, University of Washington, Seattle 5, Washington.

The topography of the Puget Sound area is due primarily to glacial action by a lobe of the Cordillerian ice sheet. The shore line is bordered by deposits of clay, sand, gravel and till, reminiscent of the glacial control. These glacier-derived sediments often form shore line cliffs 200 or more feet high.

Glacial till is a prominent source of sediments in Puget Sound and may become a part of the marine sediment in various ways. (1) The slopes may be in part composed of glacial deposits "in situ". (2) The erosion of cliffs and beaches will also be a supply of glacial sediments. (3) the streams are imposed on glacial till and will transport this material to the marine environment. (4) Slumping of the cliffs, which are composed of glacial deposits, will add to the marine sediments.

Chemically and mechanically weathered material from the basement rocks of the Cascade and Olympic Mountains contributes to the sediments as they are carried to the Sound by the numerous streams and rivers. Volcanics, from direct dust-falls and from inland erosion, probably account for some sediment supply in the Sound.

In the area of sampling (Fig. 1), between President Point on the west shore and Point Wells on the east, the bottom configuration is analogous to the steep shore bluffs. The eastern underwater slope is generally steep and continuous with a value of 1:3.5 from a single break at about 20 feet below sea level to the base of the slope which is approximately 700 feet below sea level. A few localities have slopes of 1:1. The western slope is not as continuous, being divided into areas with different slope angles. Some portions are exceedingly steep with values as great as 1:3, others have gradual slopes with an average value of 1:15. This suggests that bathymetrically the two slopes are different (See Fig. 3). In this region the slope areas account for about one-half of the total Sound width of 3.7 miles. The mid-channel region, representing the remaining one-half, is relatively flat with a maximum relief of about 75 feet.

Method of Sampling and Analysis

Initial examination of core samples from Puget Sound indicated that extreme variability in particle size existed. It was suspected that this variability occurred over exceedingly small horizontal distances. In order to study the variability both horizontally as well as vertically, over small horizontal distances, a device was designed to simultaneously obtain three cores spaced in a triangular pattern, 1 foot apart (Fig. 2). The cores obtained by this method were cut into sections 4 cm. in length from the surface down. Thus three approximately equal surface samples and three samples for every subsequent 4 cm. in depth were obtained

for analysis. Some 60 locations on a traverse across Puget Sound have been sampled, making available for comparison the data obtained from the analysis of 180 cores. (Fig. 3 gives the location of these samples.) The sampling of approximately 18 to 20 locations in the mid-channel and on the near shore slopes is planned for the near future.

The vertical sectioning of the cores in the manner just described yielded well over 500 individual samples. Each sample was analyzed for particle size by standard methods. The material courser than 1/16 mm. in diameter was sieved mechanically, separating it into standard fractions. The material finer than 1/16 mm., previously separated from the sample by wet sieving through a 1/16 mm. sieve, was submitted to a pipette analysis for size determination. This latter method is based upon Stokes Law; that is upon the settling velocities of spheres of a given radius suspended in a fluid of known viscosity.

Since this study deals with the variation in the results obtained in the size analysis of adjacent core samples, it is essential to know the analysis error. The standard method briefly described above satisfies this condition in allowing an impartial duplicate analysis of the same sample to be run under essentially standard laboratory conditions. When the reproducibility of the results are known, it is possible to differentiate between inconsistencies due to analysis and the actual variation between samples.

Duplicate analysis of 20 samples indicated that the analysis error was very small, with an average reproducibility for any one size determination of ±0.2 percent. There was very little divergence from this average, with only about 20 percent exceeding the average by a factor of 2. The probabilities are thus in favor of actual sample variation accounting for percentage differences between adjacent samples which exceed ±0.4 percent.

Initial Results

In order to present a summation of the results obtained, the east-west traverse of the Sound has been divided into three general areas. The eastern and western slope area from sea level down to about 500 feet below sea level represents one division. The lower portion of both slopes, from about 500 feet below sea level to the base of the slopes and adjacent channel areas, represents the second division. The last division is the mid-channel region.

The following table presents some of the differences in grade size percentages between the samples from the three cores obtained simultaneously at one location. The percent differences shown are thus in-

dicative of variations in particle size distribution from samples only one foot apart.

DIFFERENCES IN GRADE SIZE PERCENTAGES *

Size (mm.)	Slope			Base of Slope			Mid-channel		
	MAX. %	MIN. %	AVER. %	MAX. %	MIN. %	AVER. %	MAX. %	MIN. %	AVER. %
>4	1	<1	1	—	—	—	3	<1	<1
4–2	2	<1	1	<1	<1	<1	1	<1	<1
2–1	<1	<1	<1	<1	<1	<1	<1	<1	<1
1–1/2	1	<1	<1	3	<1	1	<1	<1	<1
1/2–1/4	18	<1	4	<1	<1	<1	<1	<1	<1
1/4–1/8	13	<1	4	5	<1	2	1	<1	<1
1/8–1/16	20	<1	5	10	<1	4	6	1	3

* These are approximations based on the analysis of cores from 36 of the 60 locations.

Very often the data from sediment size analysis are reported in terms of major fractions; such as sand-silt-clay ratios. Coarse, medium and fine classifications are often used where coarse material includes coarse sands and larger, medium material represents a composite of medium and fine sands and the fine matter is a summation of the amounts of silt and clay. Using such a coarse-medium-fine differentiation for the sediments in this study, the variations in frequency percent between categories of any two adjacent samples is markedly increased. The slope area presents a maximum variation of 33 percent for both the medium and fine fractions. The base of the slopes shows a maximum variation between adjacent samples, using this type of classification, is also significant in-maximum variation for the mid-channel is 10 percent in the medium and fine ranges. The average variation between the same categories of adjacent samples, using this type of classification, is also significantly increased. The slope area has an average variation of 10 to 12 percent, the base of the slopes 6 percent, and the mid-channel region 4 percent.[1]

Sediments are often described and/or classified according to statistical characteristics such as mode, median and quartile deviation. In view of this a few examples of the similarities and differences in these factors between immediately adjacent samples shall be presented.

Figure 4 graphically presents the data from two sample locations. Sample 6L1 is located on the east slope at about 560 feet below sea level. Sample 1P2 is from the west slope, approximately 600 feet below sea level. The first sample presents an exceptionally good match between the three adjacent cores. The modes are the same, while the maximum difference between the median diameters is very small, only 0.046 mm.

[1] The approximate variations given here are the averages of the numerical differences in the per cent of each individual category. For example: Core A—40 per cent fine sand; Core B—20 per cent fine sand; the variation in the fine sand is thus 20 per cent.

The coefficient of sorting, i.e., the log of the geometric quartile deviation ($\log\sqrt{Q_3/Q_1}$), which is indicative of the sorting of the sample, differs by a factor of 1.23. They are all normally sorted sediments ranging from a sorting coefficient of 0.428 to 0.528.

Visual inspection of 1P2 (Fig. 4), shows two fairly well matched bimodal curves. The cumulative curves also approximate one another. The median diameters differ by 0.29 mm.; both are poorly sorted with coefficients of 1.088 and 1.100.

Sample 7M1 (Fig. 5) is located on the west slope at a depth of about 500 feet. The frequency curves for the three adjacent cores are similar; however core A has a mode between 0.125 and 0.065 mm., while cores B and C have their modes between 0.065 and 0.031 mm. The median diameters are essentially the same, with only a 0.03 mm. difference. The most striking feature is shown in the numerical value for the sorting; 0.139 for core A and 0.385 for core B. They differ by a factor of 2.87, yet they all represent good sorting. All three cores are generally comparable.

Sample 3P3 (Fig. 5) shows some divergence between the three adjacent cores. There is a 10 percent difference in the frequency of the major modes. Cores A and B have modes between 0.5 and 0.25 mm. while core C has a mode between 0.125 and 0.0625 mm. This represents a difference of two standard grade sizes. The medium diameters have a maximum difference of 0.31 mm., or vary by a factor of 3.10. Sorting is essentially normal in all three cores with coefficients ranging from 0.431 to 0.597.

Sample 5L2 (Fig. 6) from the east slope at a water depth of 700 feet shows a marked visual difference. Core A is bimodal while Core B is unimodal. The median diameters and the coefficients of sorting differ by factors of 1.8 and 1.32 respectively. Core A is poorly sorted and core C is normally sorted.

Sample 1P1 (Fig. 6) taken from the east slope at a depth of approximately 500 feet shows a striking variation between adjacent cores. Core B is definitely unimodal, with the mode between 0.5 and 0.25 mm. Core C is slightly bimodal with the major mode between 16 and 8 mm. The median diameters differ by a factor of 1.8; the coefficients of sorting by a factor of 1.68. Both are poorly sorted.

The horizontal variation of the median diameters of the particles at particular depths in the cores is shown in Figure 7. Sample P6 shows a good relationship with depth between the median diameters of the three adjacent cores. The remaining samples present varying degrees of divergence in the median diameters.

Summary and Conclusions

Since the Puget Sound sediments are a composite of many sources, the sediment system is a complex one. Many of the sampling difficulties probably arise due to the glacial deposits, especially from those in situ and those added by the slumping of the shore bluffs.

From the analysis obtained thus far, it appears that the local variability increases up the slope and that maximum variations commonly occur on the upper slope regions, in areas of about 200- to 300-foot water depth. The degree of reliance for the data of any one core sample, in terms of horizontal extrapolation, decreases as the water depth decreases. It is also apparent from the data obtained that the greatest discrepancies between any two adjacent samples usually occurs in the smaller diameter sand sizes.

Differences between adjacent samples mean very little in themselves but by a continuation of systematic sampling and analysis, coupled with an analysis of variance as a statistical treatment of the data, variation may be placed on a quantitative basis. It is quite possible that definite horizontal and vertical trends in local variations may be defined. A continuation of this study may also assist in the determination of "in situ" glacial deposits, if sampling is carried out on the adjacent land in known glacial sediments.

Marked variations in the character of the sediments will affect the statistical values used to classify the sediments. The defining of the sediments in this or similar regions, by use of isolines or other convential means based on these statistical values, may be quite misleading.

This general method of sampling is not limited to the determination of local variability in physical characteristics of sediments. The sedimentary chemist may find such a study applicable as an introductory investigation of any area. The sedimentary bacteriologist and the neo-ecologist, paleo-ecologist or paleontologist studying the foraminifera and diatom distribution in sediments may consider this or some similar method useful during a preliminary investigation.

ILLUSTRATIONS

FIG. 1.—Outline map showing the sampling area.

FIG. 2.—Device for obtaining 3 simultaneous cores.

FIG. 3.—Upper figure shows sampling locations and bottom contours. Each location indicated was sampled by use of the triple coring device. The lower figure presents a profile of the sampling area.

FIG. 4.—Size-frequency polygons and cumulative curves for locations 6L1 and 1P2, 6L1 located on the east slope at 560 foot depth, 1P2 is on the west slope at a depth of 600 feet. Both show good correspondence between adjacent cores.

FIG. 5.—Size-frequency polygons and cumulative curves for locations 7M1 and 3P3, 7M1 is located on the west slope at a 500 foot depth, 3P3 is located on the east slope at 450 feet. The beginning of divergence between adjacent cores can be observed.

FIG. 6.—Size-frequency polygons and cumulative curves for locations 5L2 and 1P1. Both are located on the east slope at depth of 500 feet. Marked variations between adjacent cores can be observed.

FIG. 7.—Comparison of the median diameters of particle size for adjacent cores for four locations with depth in core. Sample P6 indicates good correspondence between adjacent cores at all depths in the core. Sample P3 (with a break in the scale) indicates good correspondence between adjacent cores on the surface; there are 3 fold differences between the median diameters of the cores at 10 and 20 cm. depths. Samples L6 and M7 show intermediate divergences with depth.

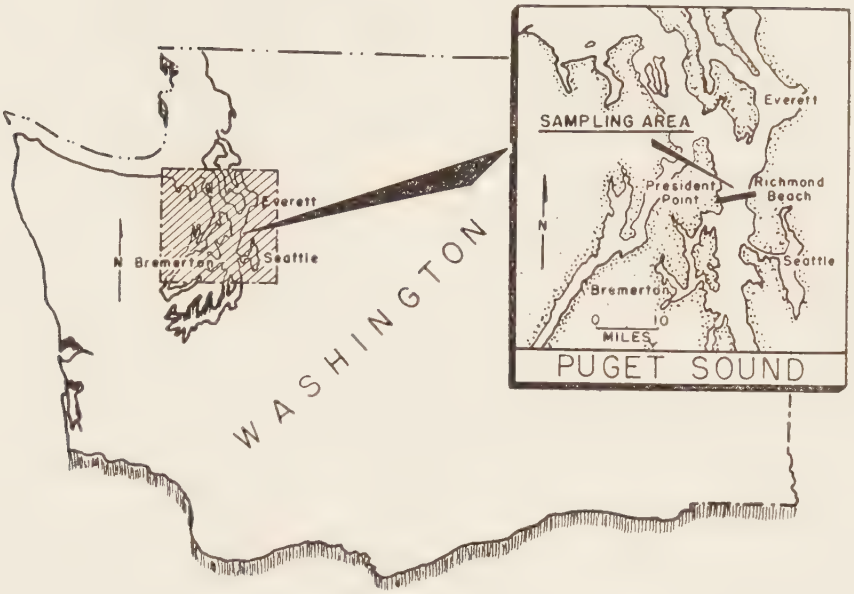

FIGURE 1

FIGURE 2

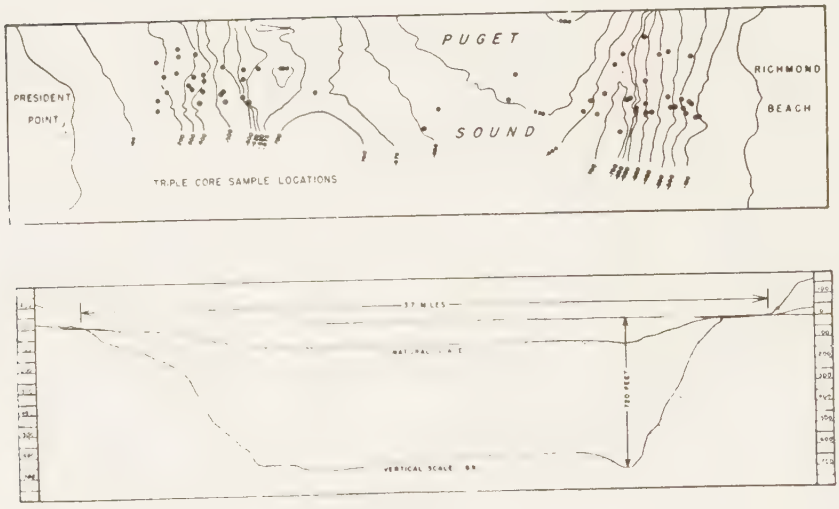

FIGURE 3

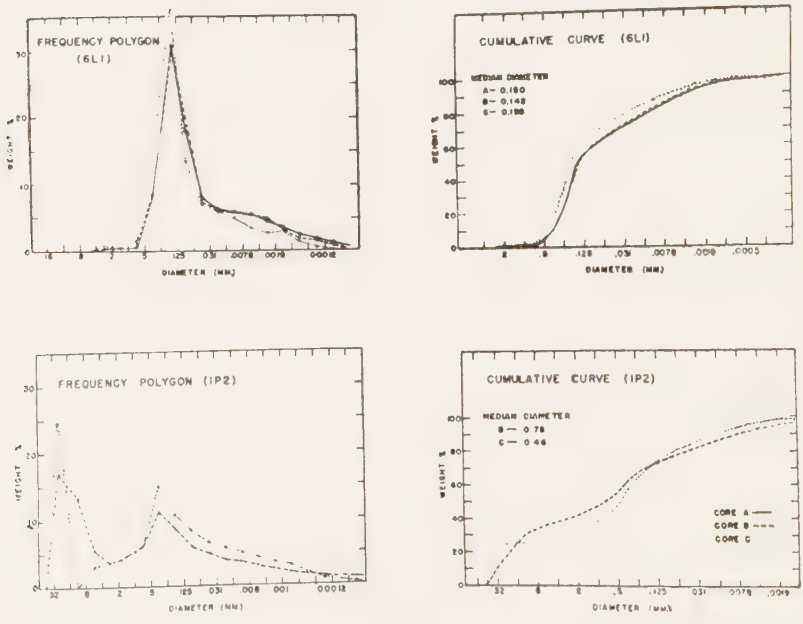

FIGURE 4

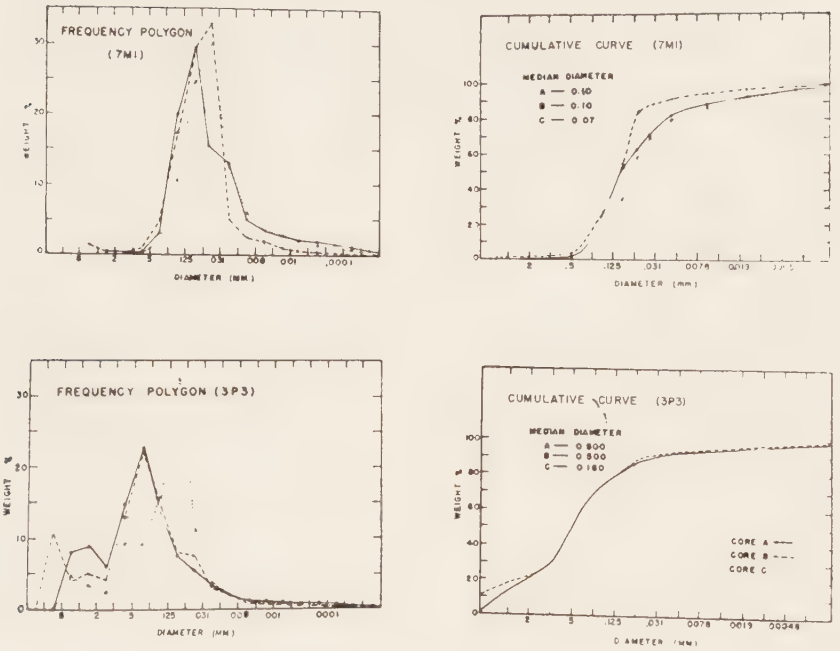

FIGURE 5

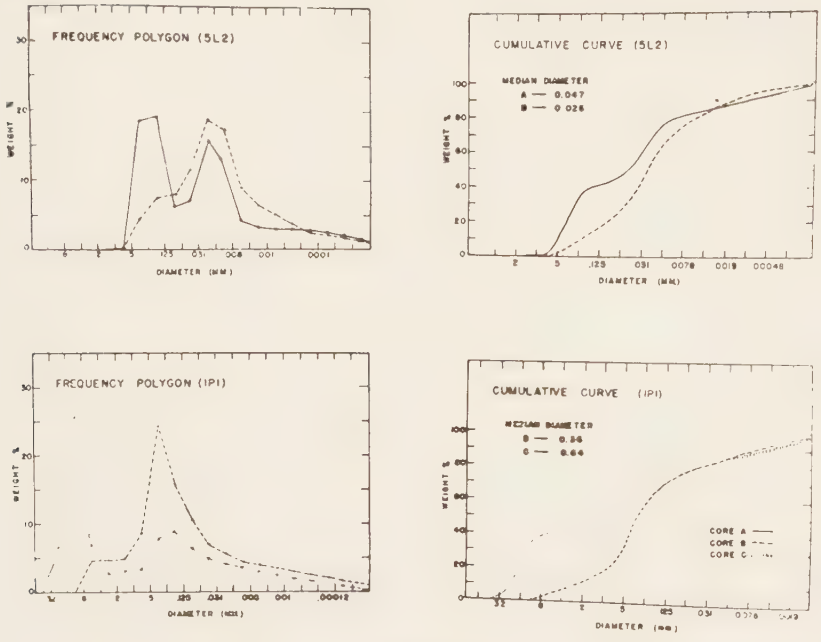

FIGURE 6

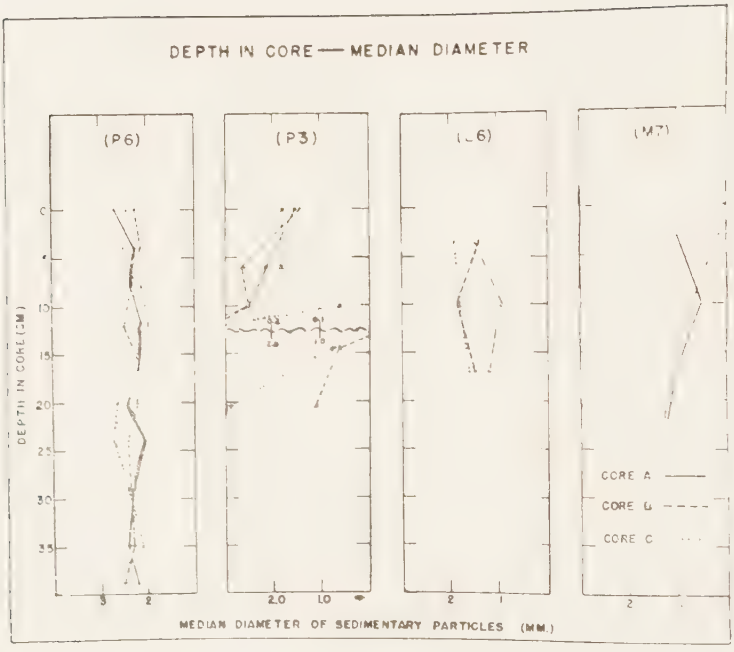
DEPTH IN CORE — MEDIAN DIAMETER
(P6)
(P3)
(L6)
(M7)
DEPTH IN CORE (CM)
0
10
15
20
25
30
35
3
2
2.0
1.0
2
1
2
CORE A
CORE B
CORE C
MEDIAN DIAMETER OF SEDIMENTARY PARTICLES (MM.)

FIGURE 7

SECULAR VARIATION OF THE ANNUAL MEAN SEA LEVEL ALONG THE JAPANESE COASTS

By Masamori Miyazaki
Kobe Marine Observatory, Japan

1. Introduction

Chief purposes of this manuscript are to analyse the time series of the annual mean sea-level computed for 11 stations (Fig. 1) along the Japanese coasts, and to investigate the origins of secular tide variations by using these data. The source material consists of continuous records (20–50 years) obtained at Aburatsubo, Kushimoto, Shimotsu, Osaka, Kobe, Uwajima, Shimizu, Hosajima, Tonoura, Sakai, and Wajima. Most of these data were already tabulated in the Tidal Record [Land Survey (1), Geographical Survey Institute (2), and the Tidal Observations Imperial Marine Observatory (3), CMO (4)].

The variations of annual mean sea-level at these stations are shown in Figure 2, which suggest the existence of the progressive and periodic variations. Especially, the progressive trends are clearly shown in these figures, and are the order of a few millimeters per year at most stations. Besides them, the sudden fall of about 1.3 m. was observed at Aburatsubo in 1923 accompanied with the Kwanto Earthquake, and similar changes took place at Shimizu in 1946 by the Nankaido Earthquake.

2. Progressive Variations

Several methods are now available to compute the secular trends from the given time series. In this paper, the expansion in orthogonal polynomes

$$f(t_1 n) = a_1 t + a_2\left(t^2 - \frac{n^2-1}{12}\right) + a_3\left(t^3 - \frac{3n^2-7}{20}\,t\right) + \cdots$$

is used for this purpose, where $f(t_1 n)$ is the annual mean sea-level, t, the time in year measured from the central instant, n, the number of years. a_1, a_2, a_3 are constants.

This method is very convenient since the significance can be checked for each order term. Computations are made for these curves, and we find that, excepting Kobe, the first and second order terms are reliable at the significance level of 5%. The dashed curves in Figure 2 represent the progressive trends computed by this method.

The dashed curve extremely rises at Osaka by the local land subsidence in the western part of the City. The total amount of variation in 19 years (1926–44) is nearly 110 cm., or 6 cm. per year. At other stations, the rates at which the sea level changes are within 1 cm/year or so, except for the sudden or rapid changes accompanied with the great earthquakes (Aburatsubo, Shimizu, Shimotsu).

3. Periodic Variations

At first, we eliminate the progressive variations from the observed series of the mean sea-level. These residuals really make the significant variations or not. The check is easily made by plotting the correlograms (Fig. 3), and we find that the variations are existent at the significance level of 5%. Figure 3 also suggests the existence of the periods 11–12 year and 18–19 year.

The exact periods will be determined by the usual method of periodgram analysis. According to the computed results, the most probable periods are

11.6 and 18.6 years for Kushimoto, and
11.4 and 18.6 years for Tonoura.

Amplitudes of these variations are significant (significance level 5%) at these stations. Besides, the amplitude of 9.3 year variation is larger than that of 18.6 year variation at Tonoura, which means the existence of bitide for the 18.6 year tide.

The amplitudes and phases ($T = 0$ at 1940) of these periodic variations are computed for several stations, and shown in Table I. These coefficients are corrected and the effects of other periods are eliminated. The statistical tests are applied according to Ogawara's method (5), and insignificant variations are omitted there.

These results are not in good agreement with those computed by Kawakami (6) chiefly because of his neglect of 11.5 year variation.

4. Effects of the Land Deformation

The land deformation is considered to be the effective origin of the sea-level variations. The results of the precise levelling carried out by the Geographical Survey Institute will be available to ascertain the relation between them.

(i) Aburatsubo—The precise levelling is frequently carried out along the route Tokyo-Aburatsubo [cf. Yamaguchi (7)]. These results fairly resemble the secular trends shown in Figure 2. However, the correlation coefficient between the leveled height of the datum line and the corresponding annual mean sea-level is

$$r = -0.59 \qquad (n = 6)$$

which shows that the linear correlation is insignificant for the year-to-year variations of the uncorrected sea-level.

(ii) Kushimoto—The datum line falls 17.55 cm. from 1900 to 1928, while the mean sea-level rises 20.0 cm. in this period.

(iii) Shimotsu—The datum line falls 27.5 cm. from 1928 to 1950, and the mean sea-level rises 25.2 cm. in this period.

(iv) Uwajima—The bench mark No. 4589, situated in Uwajima City, rises 8.9 cm. in the period 1897–1935, and falls 4.3 cm. in the period 1935–47. These results are in fair agreement with the progressive sea-level variation shown in Figure 2.

(v) Tonoura—The datum line falls 5.0 cm. from 1944 to 1950, while we have the gradual rise of the progressive sea-level trends (about 3 cm.) in this period.

Thus, the vertical land deformation is likely to be closely related with the progressive sea-level variations. However, the relations are doubtful for the year-to-year variations.

5. Tide of 18.6-Year Period

The longitude of the moon's ascending node varies with the 18.6-year period, and accordingly the obliquity of the moon's orbit varies from 18.3 to 28.6. It is the origin of the 18.6-year period tide. Therefore, it is included in Darwin's expansion of equilibrium tides. But the theoretical amplitudes are, similarly as the other component tides, generally smaller than the computed values.

6. Oceanographical Effects

The oceanographical effects are also thought to be important. However, at least until now, the numbers of the oceanographical surveys are too small to find out the mutual relations. The only available data are found for the variations of Kushimoto.

The repeated observations are made for the fixed section off Shiono-Misaki, and the year-to-year density variations in the upper layers can be computed for the period 1925–31. The sea-level variations caused by this origin h_1 are computed by Nomitsu's method (8), and shown in Table III. The variations of the Kuroshio currents are also investigated for this region by Uda (9) (10), and the sea-level rise measured from the current axis is easily computed by the formula

$$h_c = -\frac{w}{g}\sin\varphi\, L\bar{u}$$

where $\bar{u}$ is the annual mean speed of the Kuroshio at the surface of this area, and L is the corresponding current width. The results of computation are also shown in Table III.

We now eliminate the effects of the statical pressure from the residual sea-level variation at Kushimoto. The correlation coefficient between h_d and this quantity

$$r = 0.61 \qquad (n = 7)$$

is not significant. However, when we further deduct h_d from this quantity, the correlation between h_c and the last quantity is significant at the level of 2%, since we have

$$r = 0.84 \qquad (n = 7)$$

It means that the residual sea-level change in this period is chiefly caused by the variations of pressure, water density, and ocean currents.

7. Meteorological Effects

(i) Pressure—The pressure change naturally causes the variation of the sea-level. The sea-level rise of 1 cm. nearly corresponds to the pressure fall of 1 mb. The fluctuation of the annual mean sea-level is generally within 1 mb. and the corresponding sea-level change will be also the order of 1 cm. or less.

(ii) Winds—According to Shimizu (11), the sea-level change caused by winds is estimated to be the order of 1 cm/m/sec or less for the most effective wind directions. Therefore, the wind effects will be disregarded for our purpose, since the fluctuation of the annual mean wind speed is within tens of centimeters.

Effects of other elements (precipitation, melting of polar ice, etc.) are supposed to be too small to be taken into account.

8. Conclusions

(i) The annual mean sea-level at the stations along the Japanese coasts make the progressive and periodic variations. The progressive changes are within 1 cm/year excepting Osaka (6 cm/year), and the periodic changes (9.3, 11.5 and 18.6 years) have the magnitudes within a few centimeters.

(ii) The progressive changes are chiefly caused by the vertical land deformation: the periodic changes are likely to be chiefly caused by astronomical, oceanographical, and meteorological origins.

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TABLE I

PHASES AND AMPLITUDES OF THE PERIODIC VARIATIONS

STATION	9.3 YEAR		11.5 YEAR		18.6 YEAR	
	AMP. cm.	PHASE	AMP. cm.	PHASE	AMP. cm.	PHASE
Kushimoto	—	—	2.10	285.5	1.58	180.6
Shimotsu	2.18	197.5	1.56	21.1	1.89	164.8
Osaka	2.82	298.4	3.25	3.9	1.93	31.3
Kobe	2.54	104.0	2.04	334.1	3.16	340.8
Hosojima	1.85	87.4	—	—	—	—
Tonoura	1.57	112.2	0.81	249.0	1.16	245.1
Sakai	—	—	1.36	154.0	—	—
Wajima	1.03	259.1	1.46	325.4	0.74	129.2

TABLE II

THEORETICAL AMPLITUDES OF THE 18.6 YEAR TIDE

STATION	AMPLITUDE (cm.)	STATION	AMPLITUDE (cm.)
Kushimoto	0.5	Kobe	0.1
Shimotsu	0.3	Tonoura	0.0
Osaka	0.1	Wajima	0.8

TABLE III

EFFECTS OF OCEANOGRAPHICAL ELEMENTS ON THE ANNUAL MEAN-SEA LEVEL AT KUSHIMO

YEAR	RESIDUAL CHANGE OF SEA-LEVEL	MEAN PRESSURE	h_1	h_c
	cm.	*mm. Hg*	*cm.*	*cm.*
1925	3.9	760.6	−3.3	5.8
1926	−0.7	60.9	−6.5	6.3
1927	0.7	60.5	−6.4	8.3
1928	2.6	60.7	−2.3	11.0
1929	−1.1	60.7	−6.9	7.7
1930	1.3	61.0	4.3	16.0
1931	2.8	60.8	1.0	15.4

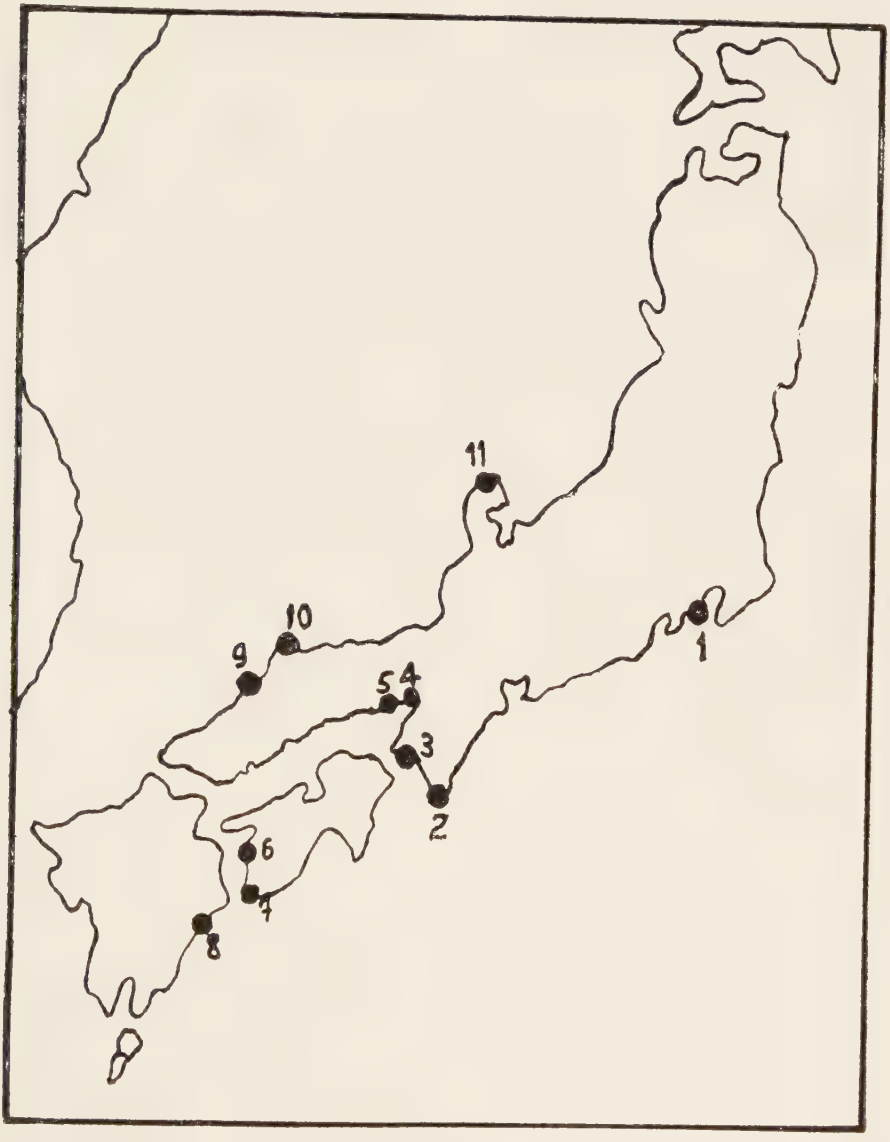

FIGURE 1

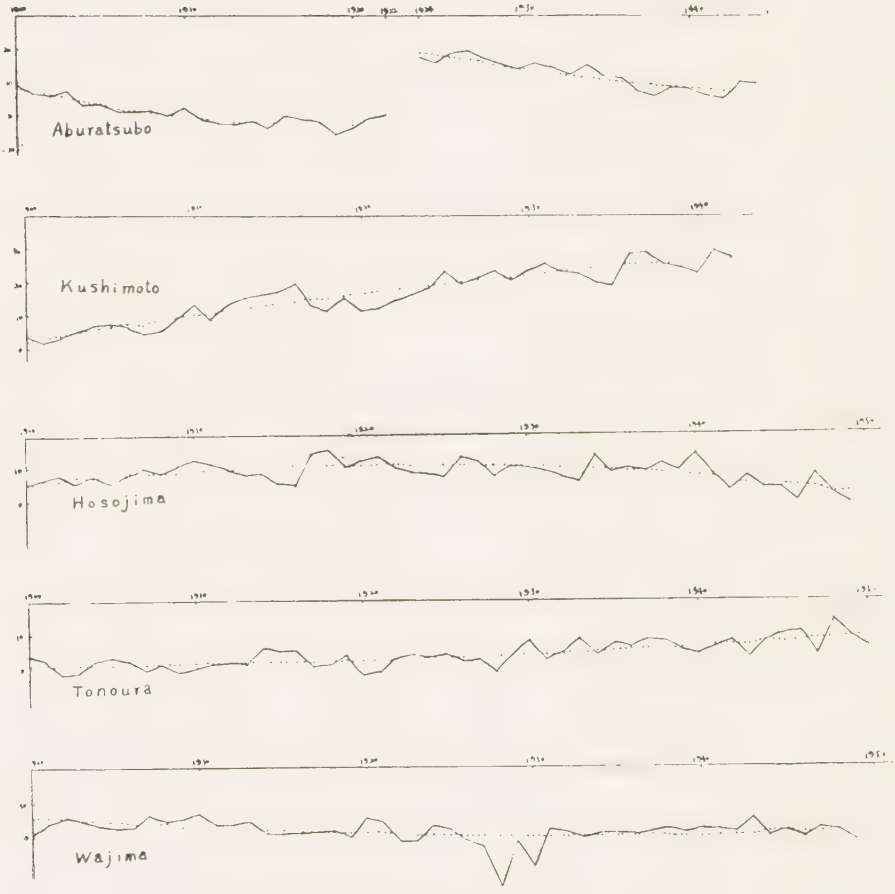

FIG. 2.—Variations of the annual mean sea-level (solid curves) and their progressive trends (dashed curves).

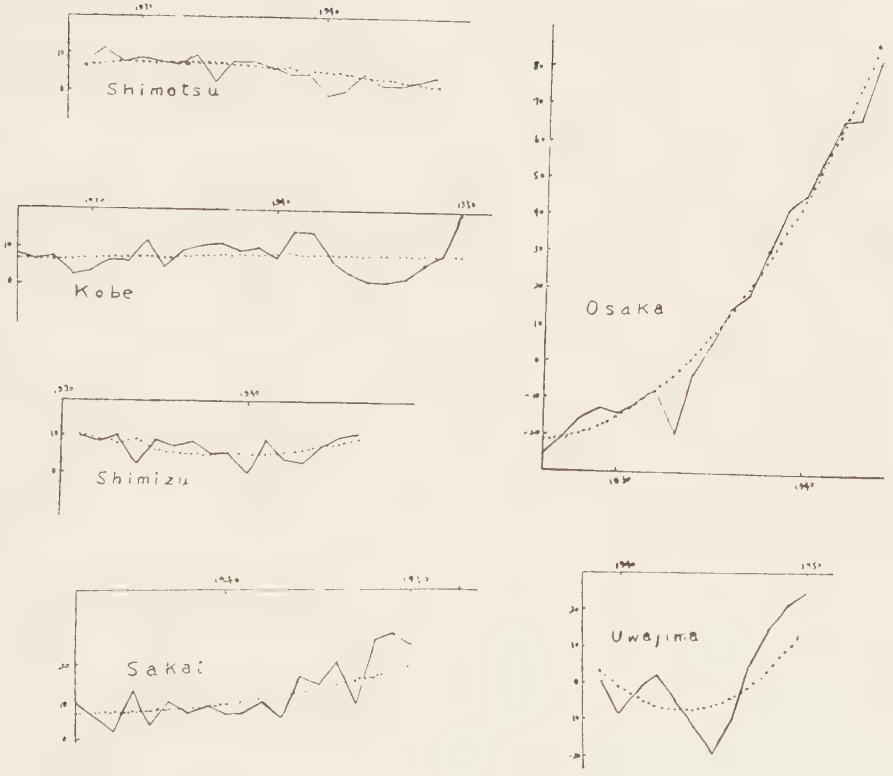

FIGURE 2 (*continuation*)

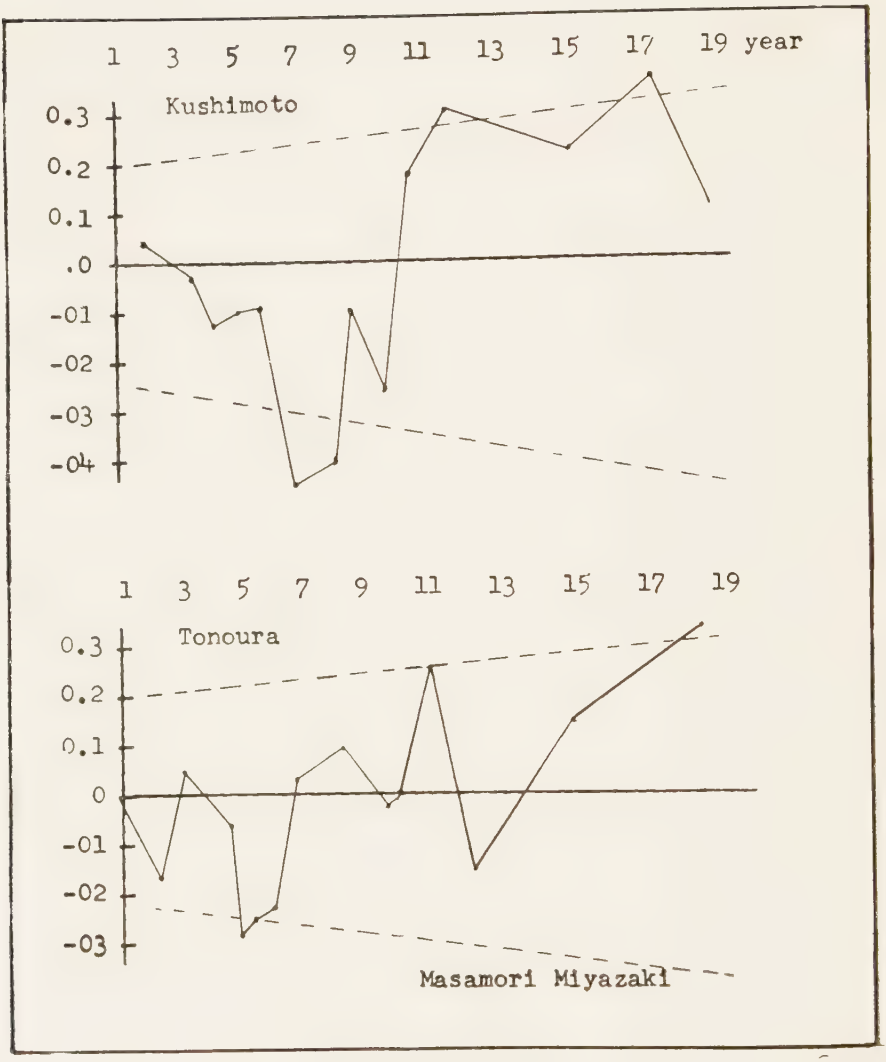
1 3 5 7 9 11 13 15 17 19 year
Kushimoto
0.3
0.2
0.1
.0
-01
-02
-03
-04
1 3 5 7 9 11 13 15 17 19
Tonoura
0.3
0.2
0.1
0
-01
-02
-03
Masamori Miyazaki

FIGURE 3

SUBMARINE CANYON INVESTIGATIONS

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SURFACE TEMPERATURE AND SALINITY IN THE SOUTHWEST PACIFIC OCEAN

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Abstract

From material recently collected, the hydrology of surface waters in seas around New Zealand is discussed in a series of papers to be published in forthcoming issues of the *New Zealand Journal of Science and Technology*. The disposition of mean monthly sea surface isotherms is described over an area from the East Australian coast to the 180th meridian between latitudes 20°S and 46°S. Differences between these patterns for individual years and the charts showing mean monthly isotherms published by the United Kingdom Meteorological Office, are defined and discussed in terms of climatological factors. These patterns are also discussed in terms of oceanic circulation and, in particular, features of the flow of subtropical water southwards off the east coasts of Australia and New Zealand are described. With the aid of thermograph records obtained on transTasman and tropical commercial routes, the fine temperature detail associated with the water masses (defined by the mean patterns), and their boundaries, are described. Similar records, obtained in New Zealand coastal waters, establish the relation between water circulation and bottom topography, and define areas of upwelling, and the distribution of subtropical, subantarctic, and coastal water types.

To a more limited degree, salinity in the various water masses defined by the temperature patterns is also discussed.

SECULAR TRENDS AT EAST AUSTRALIAN COASTAL STATIONS: 1942–1952

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I. Introduction

A phenomenon of extreme importance to the oceanographer working upon fisheries problems is the occurrence of long term trends in hydrological conditions at any region.

As part of its coastal oceanographical programme the C.S.I.R.O. Fisheries Division has, since 1942, maintained monthly to fortnightly sampling at a number of stations situated some five miles offshore in about 60–70 metres of water. (Fig. 1.)

At each of these stations samples for temperature, chlorinity, dissolved O_2, pH, inorganic phosphates, organic phosphorus and nitrate nitrogen have been collected at 10-metre depth intervals to 50 metres.

Within the time limits of this paper it is proposed to demonstrate long term trends in hydrological properties at a number of these stations, and to discuss possible causes of such trends.

II. Data and Methods

The data and the methods used in their collection and analysis have been given in Oceanographical Station Lists of the C.S.I.R.O. Vols. 4 and 14.

In order to simplify the presentation of the trends, the data have been divided into a summer period, October to April inclusive, and a winter period, May to September, on the basis of the annual temperature cycle in these waters. During the summer period the water temperature increases or remains at a stationary maximum value, whilst during the winter it decreases or remains stationary at a minimal value.

The vertical water column at each station has been subdivided into a surface zone, in which sampling at 0, 10 and 20 metres depth are included and a bottom zone in which sampling at 30, 40 and 50 metres depth are included. Surface or bottom values of any hydrological property are thus the A.M. of the 0, 10 and 20 or the 30, 40 and 50 metre values respectively.

III. Secular Trends at the Port Stephens, Port Hacking and Maria Island Coastal Stations

In order to illustrate the latitudinal spread of the trends exhibited by east Australian coastal waters, and also to provide as long a time span as possible, only data from the three earliest established coastal stations in New South Wales and Tasmania will be considered in this section.

Fig. 2 shows how the mean summer and winter surface and bottom nutrient conditions at the Port Hacking station have varied over the period 1943 to 1952. There is clear evidence of a gradual rise in inorganic and total phosphorus for both surface and bottom layers, with little difference between winter and summer conditions. Nitrate nitrogen values have also risen during the same period, but only in the bottom layers.

Fig. 3 demonstrates clearly the gradual decrease in $Cl^{o}/_{oo}$ associated with an increase in the rainfall at the Port Hacking coastal station during the same period. However, it is clear that the summer bottom $Cl^{o}/_{oo}$ was decreasing well in advance of the 1948 increase in summer rainfall. At the Port Stephens coastal station (Fig. 4) there is evidence of an increase in inorganic and total phosphorus from 1945 to 1950, but after that year the values have remained steady. It is to be noted, however, that the magnitude of the increase is much less than at the Port Hacking station. Moreover, nitrate values have decreased, except for the rather inexplicable increase in the bottom winter waters. At the same station the $Cl^{o}/_{oo}$ of surface waters has been greatly affected by land runoff (Fig. 5). However, it is important to note that the $Cl^{o}/_{oo}$ of the summer bottom waters has varied little during the period.

Off Maria Island (Fig. 6), the inorganic phosphates have increased since 1946 to a maximum in 1950, but have remained at this level since that year. The total phosphorus increase parallels that for inorganic phosphate. There appears to have been little change in the nitrate nitrogen of these waters during the same period.

The $Cl^{o}/_{oo}$ of these waters (Fig. 7) has increased at a steady rate since 1947 and this is true of both summer and winter periods. The decrease in rainfall particularly during the winter period is apparent.

It is clear then that at each of these three coastal stations at different latitudes along east Australia, there has been an increase in the phosphate content, both in the inorganic and organic form, over the past 7–10 years. The nitrate nitrogen has increased only at the Port Hacking station and has decreased at the other two stations.

For the New South Wales stations, the decrease in chlorinity of the surface waters particularly has been associated with increases in rainfall, but on the other hand, at the Maria Island station there has been an increase in $Cl^{o}/_{oo}$ accompanied by a decrease in rainfall.

IV. Factors of Possible Importance in the Genesis of these Trends

(a) Riverine dilution and nutrient enrichment of coastal waters.

The parallelism between surface $Cl^{o}/_{oo}$ and rainfall trends at the three stations considered in the previous section, suggests that land drainage can greatly affect the $Cl^{o}/_{oo}$ of these coastal waters.

The considerable scatter evident in the plotting of the relationship between rainfall and coastal surface $Cl^{o}/_{oo}$ in east Australian waters (Fig. 8), is not unexpected, because of the varying time lag between rainfall and its effect as riverine discharge on coastal $Cl^{o}/_{oo}$ and also because of the varying depth to which such discharges are mixed into the coastal water structure. However, it is clear that surface waters are diluted by riverine discharge with increasing effectiveness as the rainfall increases. Moreover, there is clear evidence of the existence of two principal surface water masses, a New South Wales above 37°S and an eastern Tasmanian below 37°S. Is it possible that these riverine discharges could vary the phosphate levels of these coastal waters to the extent that has been experienced at the three stations discussed in Section III?

In Fig. 9, the relationship between inorganic phosphates and $Cl^{o}/_{oo}$ at the Port Hacking station is shown. It is clear that surface and bottom waters exhibit a different $Cl^{o}/_{oo}$-phosphate relationship.

In the surface layer a decrease in $Cl^{o}/_{oo}$ from 19.70 to $19.40^{o}/_{oo}$ is accompanied by a rise in inorganic phosphates of 6μg P/L. Assuming that the decrease in $Cl^{o}/_{oo}$ is due to land drainage and that the rise in inorganic phosphates has been wholly an effect of such riverine discharges, then the phosphate concentration in the discharge would have to be about 400μg P/L. This figure is about 10 times greater than the maximum phosphate level in coastal rivers of the phosphate rich northern New South Wales region and about 40 times greater than the rivers immediately adjoining Port Hacking.

In the bottom waters the decrease in $Cl^{o}/_{oo}$ from 19.70 to 19.53 is paralleled by a rise in inorganic phosphates of 9μg P/L. This would imply a phosphate concentration of 1200μg P/L in the diluting water, which phosphate concentration is quite impossible.

It is apparent therefore that whilst land drainage can modify the $Cl^0/_{00}$ structure of coastal waters, its role in the gradual increase in phosphate levels at coastal stations since 1945 cannot be a direct one.

(b) Lateral movement of slope waters into the coastal region.

During 1940–42 F.R.V. "Warreen" was able to sample simultaneous coastal and shelf stations at frequent intervals off Port Hacking. Fig. 10 shows the relationship between inorganic phosphates and $Cl^0/_{00}$ for slope waters and Fig. 11 for the bottom coastal waters sampled during this period. The regression line for the slope data above $10\mu g/L$ PO_4P has been calculated and superimposed on the coastal water diagram. The coastal data fits this regression line fairly well and it is highly probable that slope waters of varying depths have periodically invaded these coastal regions during this period.

Since that time, the systematic collection of data at the Port Hacking coastal station has revealed that these slope water invasions of the coastal region are a common feature of the summer period, particularly during the period of high vertical stability. These slope waters are comparatively rich in phosphates with lower $Cl^0/_{00}$, temperature and dissolved O_2 than the coastal bottom waters. Could the rise in inorganic phosphates and the decrease in $Cl^0/_{00}$ in the bottom waters at the Port Hacking station during 1943–1952 be an effect of more frequent invasion and more effective assimilation of such slope waters into the structure of coastal waters?

Whilst lack of information about the dynamical continuity between slope and coastal regions makes the examination of such a possibility very difficult, there are certain significant features in the trend curves at the Port Hacking station which favour such a theory.

Referring again to Fig. 3, it can be seen that the mean summer bottom temperatures have decreased fairly consistently from 1943 to 1949, and risen rather rapidly since that year. This trend is paralleled by the $Cl^0/_{00}$ of these waters and, whilst the surface dilution of these waters during the 1949 period and onward, may have contributed in some measure to the later portion of this trend, the fact that this decrease commenced in 1944 would indicate some more fundamental cause of the phenomenon. Assuming then that the decrease in summer bottom temperature and chlorinity has been little influenced by the rainfall cycles during the period, there seems good evidence to support the theory of more effective assimilation of low temperatures and chlorinity slope waters into the structure of the Port Hacking bottom coastal waters during 1943–1949.

(c) Increase in phosphate content of slope waters.

Fig. 12 shows the relationship between total phosphorus and oxygen saturation values of the Port Hacking summer bottom waters during 1943–1952.

By differentiating the data into years, it is possible to see clearly that these bottom waters have changed their O_2–total phosphorus relationship quite considerably during the period.

To better illustrate this, two envelopes have been entered, one labelled A, containing a majority of the data subsequent to and the other labelled B, prior to that year. At any given oxygen saturation level it is clear that the total phosphorus content has increased over the period. Unfortunately one cannot assume from this that the parent slope waters have also changed their total phosphorus and dissolved O_2 content in a similar fashion at the depth of origin of these coastal intrusions. There would, however be no reason to suppose that the east Australian slope waters would not undergo long term changes in hydrological properties, and it is quite possible that an increase in the nutrient level of the parent slope waters themselves has contributed to these coastal water trends.

(d) Replacement of local coastal waters by a foreign water mass of higher nutrient content.

Along the east Tasmanian coast the evidence from coastal observations suggests that lateral movement of deep offshore waters into coastal regions is extremely rare, largely because it is suspected that a slope current is only weakly developed. One cannot assume therefore that the same processes have contributed to the secular trends at the Maria Island station, as have been considered responsible in more northern latitudes. It is significant too that the rise in phosphates and total phosphorus has been accompanied by an increase in $Cl^o/_{oo}$ and temperature during the winter period, particularly from 1947 to 1951. On the evidence it was considered probable that in this region the secular changes were due to a gradual displacement of the original east Tasmanian water mass of 1945 by a new water mass of higher $Cl^o/_{oo}$, temperature and nutrient content.

In Fig. 13 the total phosphorus–chlorinity relationship of the mean summer bottom data for east Australian coastal stations is shown. It seems clear from this slide that all of the data can be developed by mixing between three primary water masses with distinct total phosphorus–$Cl^o/_{oo}$ relationship. If we examine the chlorinity–temperature relationship, Fig. 14, three primary water masses can be distinguished. It is possible to identify a New South Wales coastal and an east Tasmanian coastal water mass on their temperature, chlorinity, total phosphorus relationships, but the genesis of the third with low temperature

and chlorinity, associated with high total phosphorus characteristics is difficult to decide exactly, although such characteristics are more typical of deeper offshore waters of New South Wales than of east Tasmania.

Without sufficient knowledge of the dynamics of the New South Wales Tasman Sea, however, it is impossible to demonstrate how such a water mass could have influenced the Tasmanian coastal region.

V. Meteorological and Dynamical Changes Associated with these Trends

If we accept the proposition that the secular trends at the Port Hacking coastal station are due in large measure to variations in the amount of slope water influence, then a study of the possible factors controlling such slope water variation might eventually enable the oceanographer to predict by study of the variation in the principal controlling factors, oceanographical conditions in future seasons. For the past 10 years the C.S.I.R.O. Fisheries Division has been studying the monthly and annual variations in mean sea level at a station representative of coastal conditions off Port Hacking.

If we examine the mean summer and winter mean sea levels variations at this station during the period 1942–1952, Fig. 15, the existence of a secular trend is evident. Moreover, the magnitude of the cycle has been much greater during the summer than the winter period. The period of minimum summer mean sea levels from 1946 to 1949, corresponds to the period of lowest mean summer bottom temperatures at the Port Hacking station. There is evidence from the New South Wales coastal station of the development of a counter current flowing north, at distances of about 5 miles offshore, during the later part of the summer. The high mean sea levels normally experienced in March–April are considered to be an effect of this current along the coast. Presumably then during seasons when this counter current is strongly developed, the intrusion of slope waters is retarded because the isentropic layers are tilted down towards the coast and oppose the lateral movement of deep slope waters into the coastal region.

In Fig. 16 the relationship between mean monthly sea level and bottom temperatures at the Port Hacking station during December over the period 1942–1952 is shown. For those years when high sea levels prevailed during December and are indicative according to the theory outlined above of weak slope water influence, the mean monthly bottom temperatures are higher.

It seems clear then that the ultimate answer to both variation in slope water intrusion and the coastal mean sea level at the Port Hacking

station is linked with the variation in the development of this counter current. However, it has not been possible as yet to show any consistent relationship between the variation in this counter current and corresponding variation in the direction or strength of coastal winds. It is possible that wind conditions over the Tasman Sea proper may be more influential in this regard but scarcity of data prevents such an analysis being made.

VI. Discussion

In studying the coastal hydrology of the east Australian region with its comparatively narrow shelf and well-developed offshore current system, the extreme variability of the coastal environment and the major effects of the offshore current on such variation, are evident. This paper serves to illustrate another longer term variation, which is important to the fisheries of the region and which has had very widespread effects.

It is obvious, however, that to advance beyond the mere description of coastal events, and of their probable genesis, to a more complete and perhaps useful stage, requires the simultaneous collection of information upon the dynamics and hydrological structure of the offshore in addition to the onshore regions. Moreover, it is clear that the elucidation of the causes for long term fluctuations in east Australian coastal conditions requires persistent and intensive investigation not only of the coastal hydrology but also of the associated estuaries and their flood contribution, as well as of the meteorological elements, particularly wind and rainfall, which enter into these cycles.

PORT STEPHENS COASTAL STATION

Latitude: 32° 43′ S. Longitude: 152° 18′ E.

Summer Period	Temp.	Cl ‰	PO_4P	Total P.	NO_3N	O_2%
0–25 m. Mean Column						
October '45–April '46	19.51	19.27	3	9	32	87
October '46–April '47	19.70	19.60	2	7	23	94
October '47–April '48	19.34	19.63	7	16	4	98
October '48–April '49	19.22	19.62	5	9	5	100
October '49–April '50	19.53	19.52	8	19	15	96
October '50–April '51	21.64	19.52	5	16	0	98
October '51–April '52	18.62	19.63	8	14	5	(105)
October '52–April '53	20.26	19.56	5	13	3	101
25–50 m. Mean Column						
October '45–April '46	17.47	19.59	9	18	66	79
October '46–April '47	17.35	19.60	8	14	58	80
October '47–April '48	17.91	19.63	13	20	38	89
October '48–April '49	17.89	19.64	8	13	22	88
October '49–April '50	16.99	19.61	15	28	60	77
October '50–April '51	19.81	19.61	7	11	4	93
October '51–April '52	17.52	19.62	13	18	35	89
October '52–April '53	18.10	19.58	14	19	59	82
0–50 m. Mean Column						
October '45–April '46	18.49	19.43	6	13.5	49	83
October '46–April '47	18.53	19.60	5	10.5	41	87
October '47–April '48	18.63	19.63	10	18	21	94
October '48–April '49	18.56	19.63	6.5	11	14	94
October '49–April '50	18.26	19.57	11.5	23.5	38	87
October '50–April '51	20.73	19.57	6	13.5	2	96
October '51–April '52	18.07	19.63	10.5	16	20	(97)
October '52–April '53	19.18	19.57	9.5	16	31	92

PORT STEPHENS COASTAL STATION

Latitude: 32° 43′ S. Longitude: 152° 18′ E.

Winter Period	Temp.	Cl ‰	PO_4P	Total P.	NO_3N	O_2%
0–25 m. Mean Column						
May–September '45	(17.52)	(19.52)	(2)	(5)	(14)	(96)
May–September '46	16.89	19.65	3	5	10	97
May–September '47	17.98	19.61	(4)	(8)	29	95
May–September '48	(18.45)	(19.63)	(5)	(12)	(3)	(99)
May–September '49	18.05	19.36	9	16	16	95
May–September '50	18.21	19.34	8	13	30	95
May–September '51	(18.50)	(19.59)	(6)	(18)	(2)	(96)
May–September '52	19.07	19.62	6	15	8	97

25–50 m. Mean Column

May–September '45	(17.33)	(19.68)	(3)	(14)	(56)	(79)
May–September '46	16.48	19.67	2	5	19	96
May–September '47	(17.85)	(19.63)	(6)	(11)	(51)	(87)
May–September '48	(18.15)	(19.62)	(4)	(12)	(3)	(100)
May–September '49	17.90	19.51	10	15	45	91
May–September '50	18.07	19.56	11	15	54	86
May–September '51	(17.87)	(19.63)	(8)	(14)	(95)	(95)
May–September '52	18.42	19.63	8	17	21	95

0–50 m. Mean Column

May–September '45	(17.43)	(19.60)	(2.5)	(9.5)	(35)	(88)
May–September '46	16.69	19.66	2.5	5	15	97
May–September '47	(17.92)	(19.62)	(5)	(9.5)	(40)	(91)
May–September '48	(18.30)	(19.63)	(4.5)	(12)	(3)	(100)
May–September '49	17.98	19.44	9.5	15.5	31	93
May–September '50	18.14	19.45	9.5	14	42	91
May–September '51	(18.19)	(19.61)	(7)	(16)	(48)	(96)
May–September '52	18.75	19.63	7	16	15	96

PORT HACKING COASTAL STATION

Latitude: 34° 05′ S. Longitude: 151° 13′ E.

Summer Period	Temp.	Cl ‰	PO_4P	Total P.	NO_3N	O_2%
			0–25 m. Mean Column			
October '42–April '43	19.86	19.67	1	—	5	97
October '43–April '44	19.45	19.67	1	4	7	97
October '44–April '45	19.37	19.65	1	4	4	96
October '45–April '46	19.54	19.60	4	10	17	96
October '46–April '47	18.69	19.64	3	7	15	97
October '47–April '48	19.18	19.60	6	13	6	98
October '48–April '49	18.91	19.61	6	12	10	98
October '49–April '50	19.19	19.43	9	20	19	95
October '50–April '51	20.85	19.44	5	15	6	98
October '51–April '52	19.54	19.64	7	15	10	100
October '52–April '53	20.14	19.59	5	15	5	99
			25–50 m. Mean Column			
October '42–April '43	18.10	19.63	5	—	22	83
October '43–April '44	17.85	19.69	4	8	19	90
October '44–April '45	17.87	19.64	3	7	18	90
October '45–April '46	17.00	19.60	9	15	46	84
October '46–April '47	16.92	19.62	6	11	35	88
October '47–April '48	17.30	19.58	12	19	53	88
October '48–April '49	16.75	19.57	10	15	35	88
October '49–April '50	17.50	19.53	14	21	62	83
October '50–April '51	18.98	19.54	9	21	34	89
October '51–April '52	17.56	19.63	13	20	44	89
October '52–April '53	17.74	19.58	13	21	40	87

0–50 m. Mean Column

October '42–April '43	18.98	19.65	3	—	15	90
October '43–April '44	18.65	19.68	2.5	6	13	94
October '44–April '45	18.62	19.65	2	5.5	11	93
October '45–April '46	18.27	19.60	6.5	12.5	32	90
October '46–April '47	17.81	19.63	4.5	9	25	93
October '47–April '48	18.24	19.59	9	16	30	93
October '48–April '49	17.83	19.59	8	13.5	23	93
October '49–April '50	18.35	19.48	11.5	20.5	40	94
October '50–April '51	19.82	19.49	7	18	20	93
October '51–April '52	18.50	19.64	10	17.5	27	95
October '52–April '53	18.94	19.59	9	18	23	93

PORT HACKING COASTAL STATION

Latitude: 34° 05′ S. Longitude: 151° 13′ E.

Winter Period	Temp.	Cl ‰	PO_4P	Total P.	NO_3N	O_2%
	0–25 m. Mean Column					
May–September '43	15.89	19.62	5	10	15	97
May–September '44	16.84	19.70	2	9	9	97
May–September '45	17.99	19.57	3	9	21	92
May–September '46	16.98	19.67	3	6	15	95
May–September '47	16.86	19.65	5	11	31	95
May–September '48	16.59	19.62	8	12	8	99
May–September '49	17.67	19.63	9	14	9	96
May–September '50	17.90	19.44	7	19	17	99
May–September '51	17.72	19.51	8	18	16	97
May–September '52	17.53	19.47	10	16	21	89
	25–50 m. Mean Column					
May–September '43	15.74	19.69	6	11	18	92
May–September '44	16.38	19.67	4	10	17	93
May–September '45	16.54	19.58	8	15	52	82
May–September '46	16.72	19.67	4	7	27	94
May–September '47	16.17	19.63	6	10	44	91
May–September '48	16.01	19.61	9	16	20	96
May–September '49	17.04	19.63	9	16	30	91
May–September '50	17.36	19.52	11	21	48	92
May–September '51	17.27	19.56	10	20	33	90
May–September '52	16.80	19.57	15	22	54	89
	0–50 m. Mean Column					
May–September '43	15.79	19.66	5.5	10.5	17	95
May–September '44	16.61	19.69	3	9.5	13	95
May–September '45	17.27	19.58	5.5	12	37	87
May–September '46	16.85	19.67	3.5	6.5	21	95
May–September '47	16.52	19.64	5.5	10.5	38	93
May–September '48	16.30	19.62	8.5	14	14	98

May–September '49	17.36	19.63	9	15	20	94
May–September '50	17.63	19.48	9	20	33	96
May–September '51	17.50	19.54	9	19	25	94
May–September '52	17.17	19.52	12.5	18	38	89

MARIA ISLAND COASTAL STATION

Latitude: 42° 36′ S. Longitude: 148° 16′ E.

Summer Period	Temp.	Cl °/₀₀	PO_4P	Total P.	NO_3N	O_2%
		0–25 m. Mean Column				
October '44–April '45	(12.51)	(19.34)	—	—	(12)	—
October '45–April '46	(14.59)	(19.34)	(4)	(6)	(13)	(97)
October '46–April '47	13.78	19.31	4	6	12	101
October '47–April '48	14.14	19.39	9	13	12	97
October '48–April '49	13.26	19.37	8	12	5	92
October '49–April '50	(13.91)	(19.37)	(11)	(22)	(7)	(100)
October '50–April '51	14.64	19.40	8	22	7	(95)
October '51–April '52	14.31	19.54	11	(14)	10	(85)
October '52–April '53	14.65	19.40	8	17	12	101
		25–50 m. Mean Column				
October '44–April '45	(12.18)	(19.34)	—	—	(3)	—
October '45–April '46	(14.14)	(19.35)	(5)	(9)	(22)	(94)
October '46–April '47	13.11	19.30	5	7	24	99
October '47–April '48	13.59	19.39	10	14	15	92
October '48–April '49	12.80	19.41	8	13	6	95
October '49–April '50	(12.93)	(19.37)	(12)	(15)	(13)	(94)
October '50–April '51	14.16	19.44	9	21	4	90
October '51–April '52	13.89	19.51	10	(16)	12	85
October '52–April '53	13.59	19.41	11	21	25	(91)
		0–50 m. Mean Column				
October '44–April '45	(12.35)	(19.34)	—	—	(8)	—
October '45–April '46	(14.37)	(19.35)	(4.5)	(7.5)	(18)	(96)
October '46–April '47	13.45	19.31	4.5	6.5	18	100
October '47–April '48	13.87	19.39	9.5	13.5	14	95
October '48–April '49	13.03	19.39	8	12.5	6	94
October '49–April '50	(13.42)	(19.37)	(11.5)	(18.5)	(10)	(97)
October '50–April '51	14.40	19.42	8.5	21.5	6	(93)
October '51–April '52	14.10	19.53	10.5	15	11	(85)
October '52–April '53	14.12	19.41	9.5	19	19	(96)

MARIA ISLAND COASTAL STATION

Latitude: 42° 36′ S. Longitude: 148° 16′ E.

Winter Period	Temp.	Cl °/₀₀	PO_4P	Total P.	NO_3N	O_2%
		0–25 m. Mean Column				
May–September '45	(13.00)	(19.46)	—	—	(7)	(97)
May–September '46	11.57	19.33	7	9	36	99

May–September '47	12.44	19.32	6	16	23	94
May–September '48	11.43	19.35	11	14	27	(97)
May–September '49	(12.46)	(19.39)	(11)	(17)	(12)	(92)
May–September '50	13.31	19.44	10	19	20	(96)
May–September '51	13.76	(19.48)	(9)	(22)	(18)	(92)
May–September '52	12.19	19.47	11	13	20	–

25–50 m. Mean Column

May–September '45	(12.95)	(19.45)	—	—	(6)	(96)
May–September '46	11.38	19.34	7	8	51	97
May–September '47	12.48	19.34	5	14	20	94
May–September '48	11.41	19.36	11	14	29	(99)
May–September '49	(12.47)	(19.39)	(12)	(21)	(18)	(87)
May–September '50	12.85	19.47	9	16	25	(66)
May–September '51	13.73	(19.45)	(7)	(12)	(12)	(96)
May–September '52	12.25	19.47	10	10	11	-

0–50 m. Mean Column

May–September '45	(12.98)	(19.46)	—	–	(7)	(97)
May–September '46	11.48	19.34	7	8.5	44	98
May–September '47	12.46	19.33	6.5	15	22	94
May–September '48	11.42	19.36	11	14	28	98
May–September '49	(12.47)	(19.39)	(11.5)	(19)	(15)	90
May–September '50	13.13	19.46	9.5	17.5	23	81
May–September '51	13.75	(19.47)	(8)	(17)	(15)	94
May–September '52	12.22	19.47	10.5	11.5	16	- -

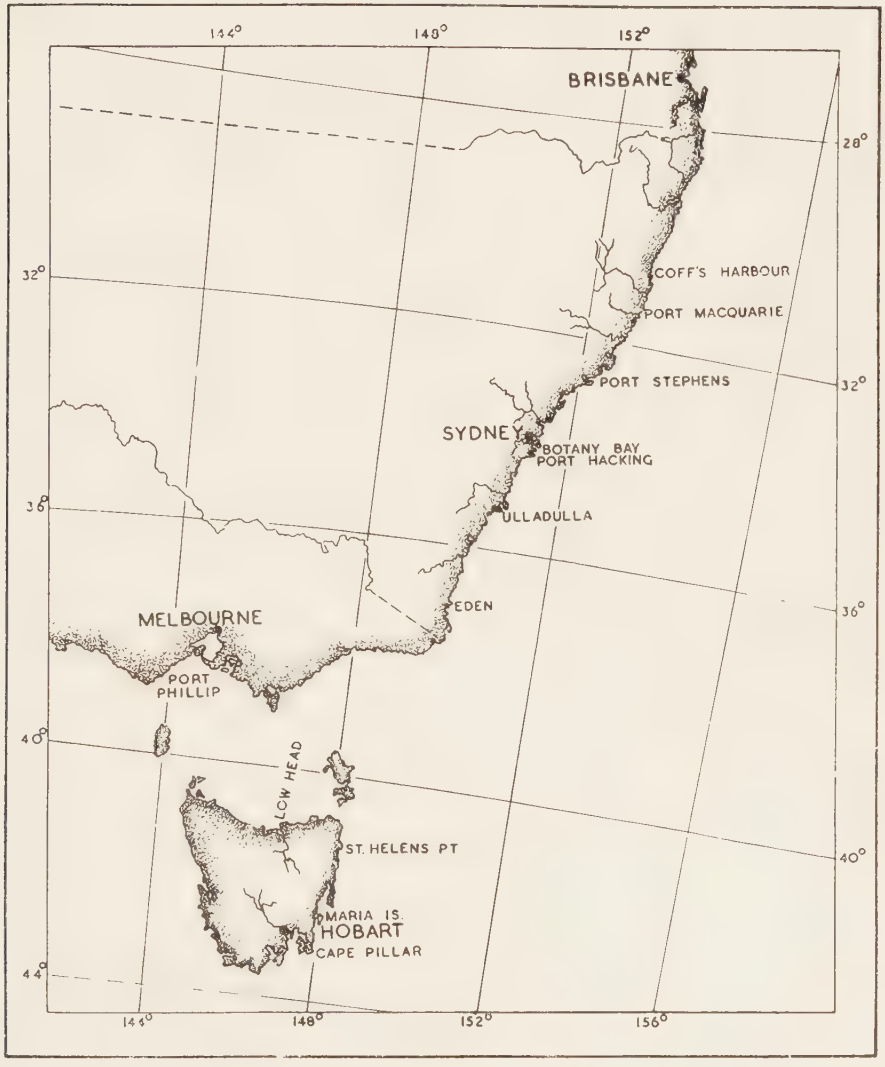

144°
148°
152°
156°
BRISBANE
28°
32°
COFF'S HARBOUR
PORT MACQUARIE
PORT STEPHENS
SYDNEY
BOTANY BAY
PORT HACKING
36°
ULLADULLA
EDEN
MELBOURNE
PORT PHILLIP
40°
LOW HEAD
ST. HELENS PT
MARIA IS.
HOBART
CAPE PILLAR
44°

FIGURE 1

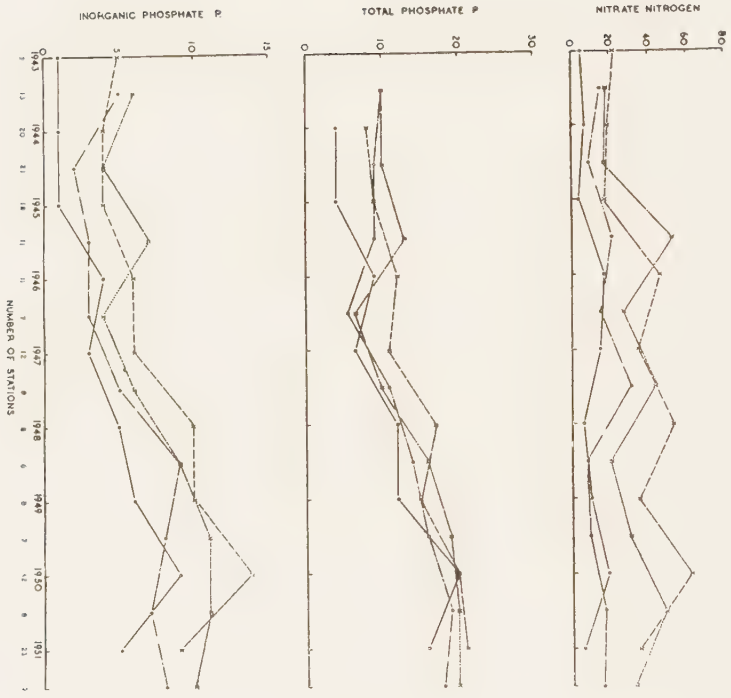

INORGANIC PHOSPHATE P.
TOTAL PHOSPHATE P
NITRATE NITROGEN
NUMBER OF STATIONS
1943
1944
1945
1946
1947
1948
1949
1950
1951

FIGURE 2

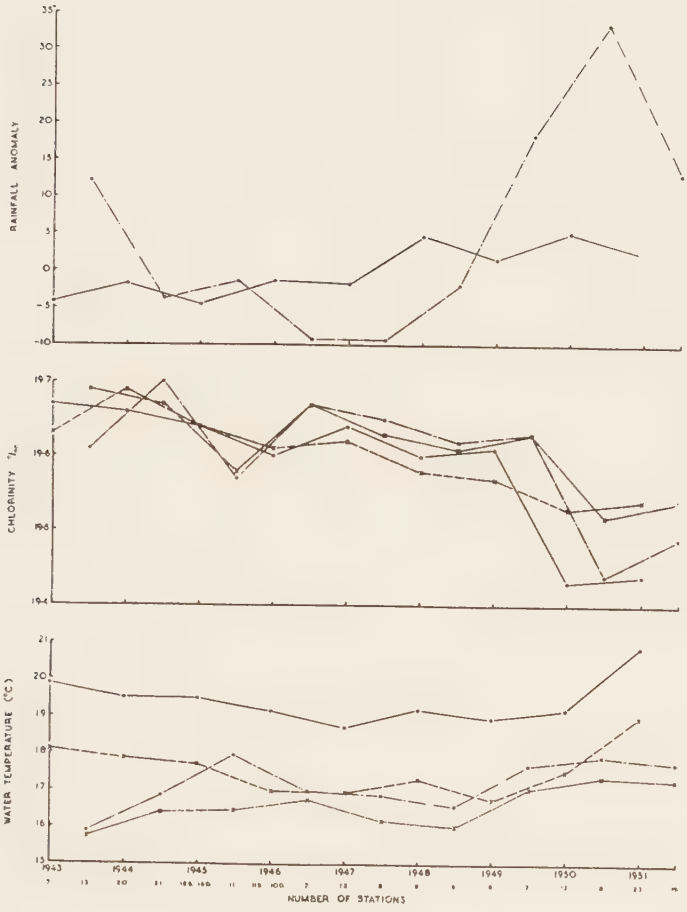

RAINFALL ANOMALY
CHLORINITY ‰
WATER TEMPERATURE (°C)
1943
1944
1945
1946
1947
1948
1949
1950
1951
NUMBER OF STATIONS

FIGURE 3

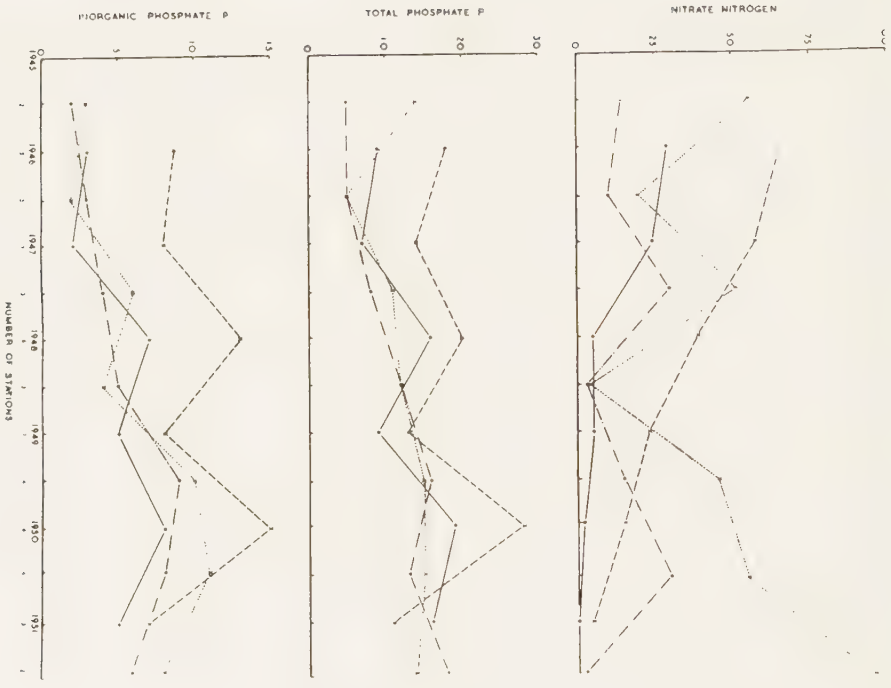

INORGANIC PHOSPHATE P
TOTAL PHOSPHATE P
NITRATE NITROGEN
NUMBER OF STATIONS
1945
1946
1947
1948
1949
1950
1951

FIGURE 4

FIGURE 5

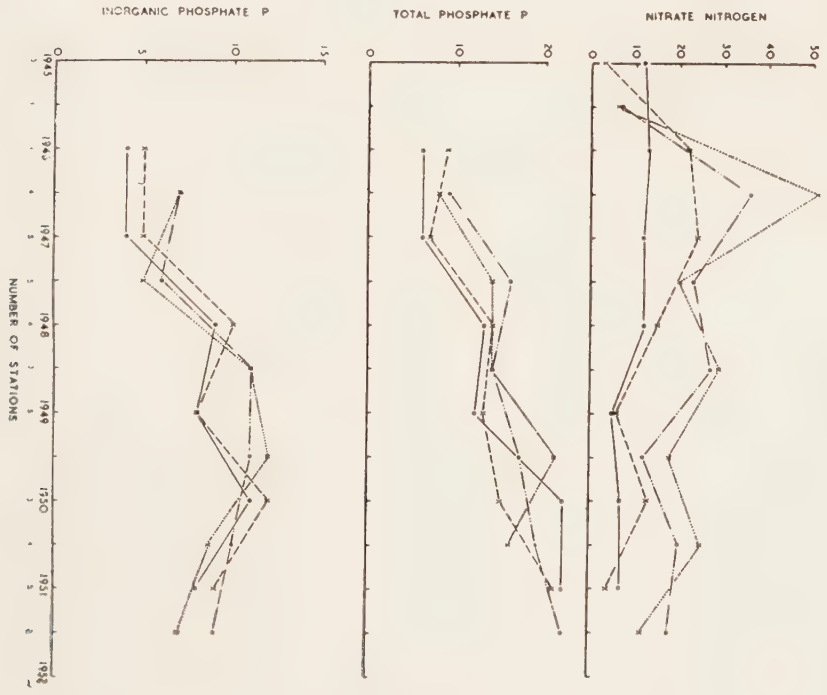


FIGURE 6

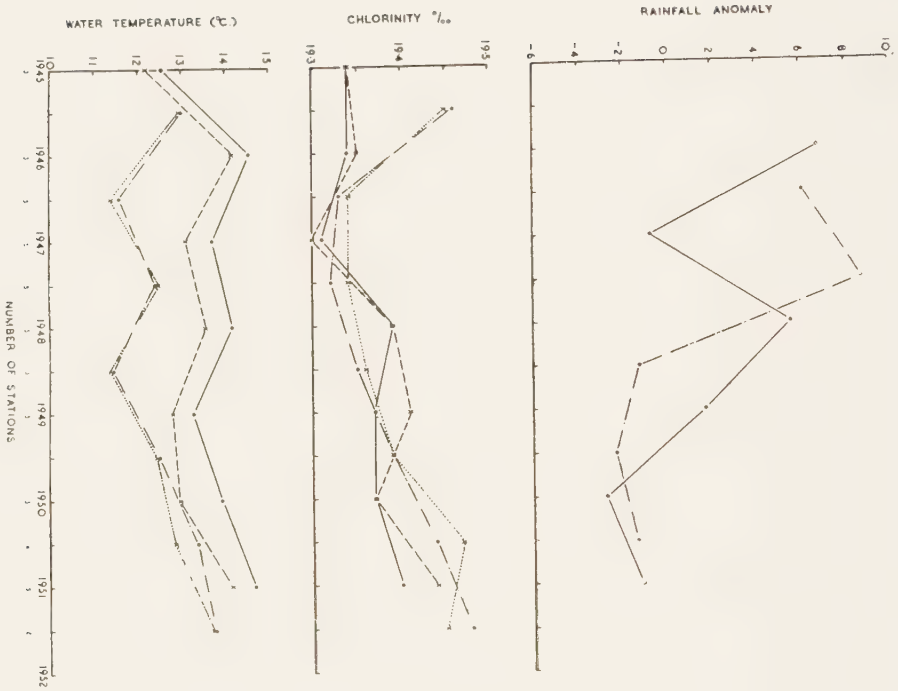

WATER TEMPERATURE (°C.)
CHLORINITY °/₀₀
RAINFALL ANOMALY
NUMBER OF STATIONS
1945
1946
1947
1948
1949
1950
1951
1952

FIGURE 7

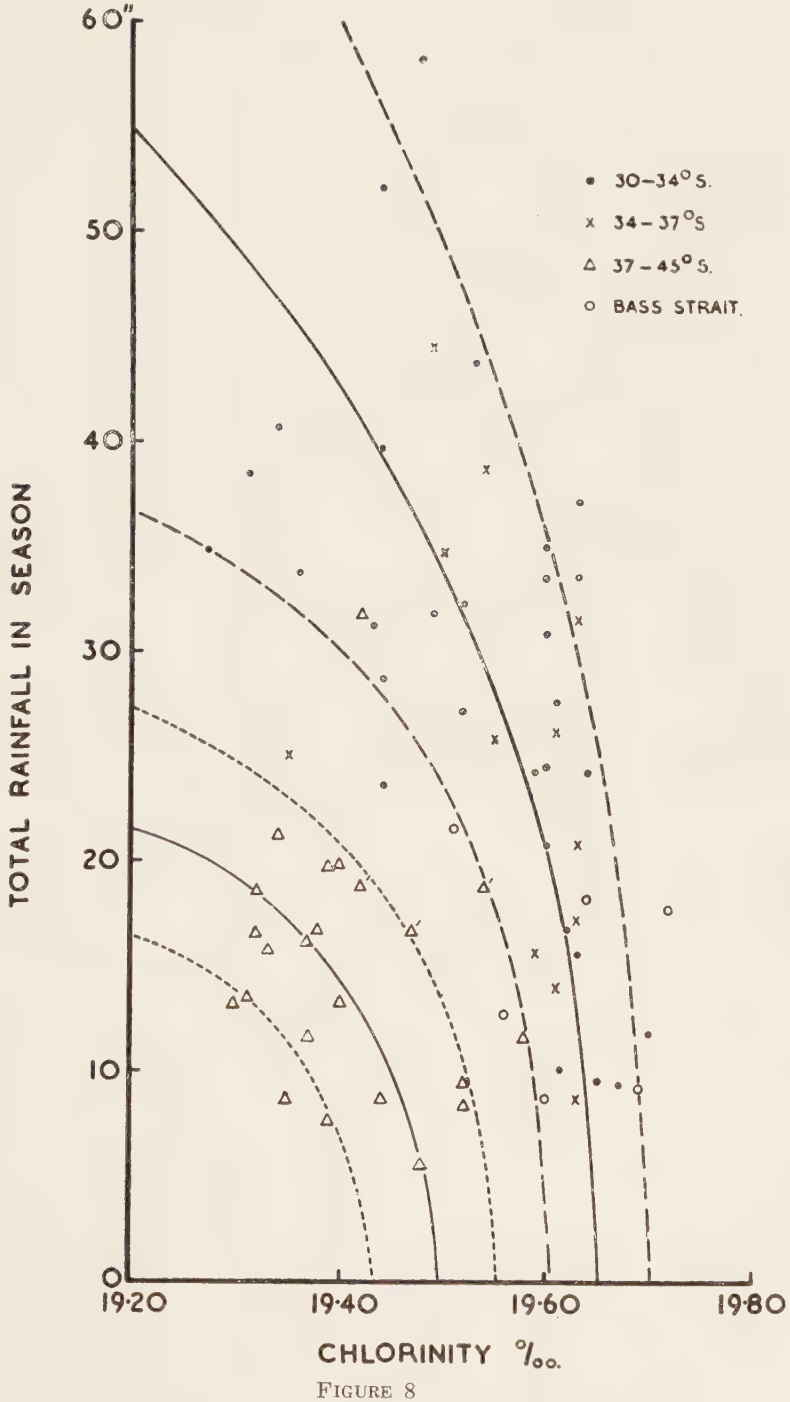

60"
50
40
30
20
10
0
TOTAL RAINFALL IN SEASON
19·20
19·40
19·60
19·80
CHLORINITY ‰
• 30–34° S.
× 34–37° S
△ 37–45° S.
○ BASS STRAIT.

FIGURE 8

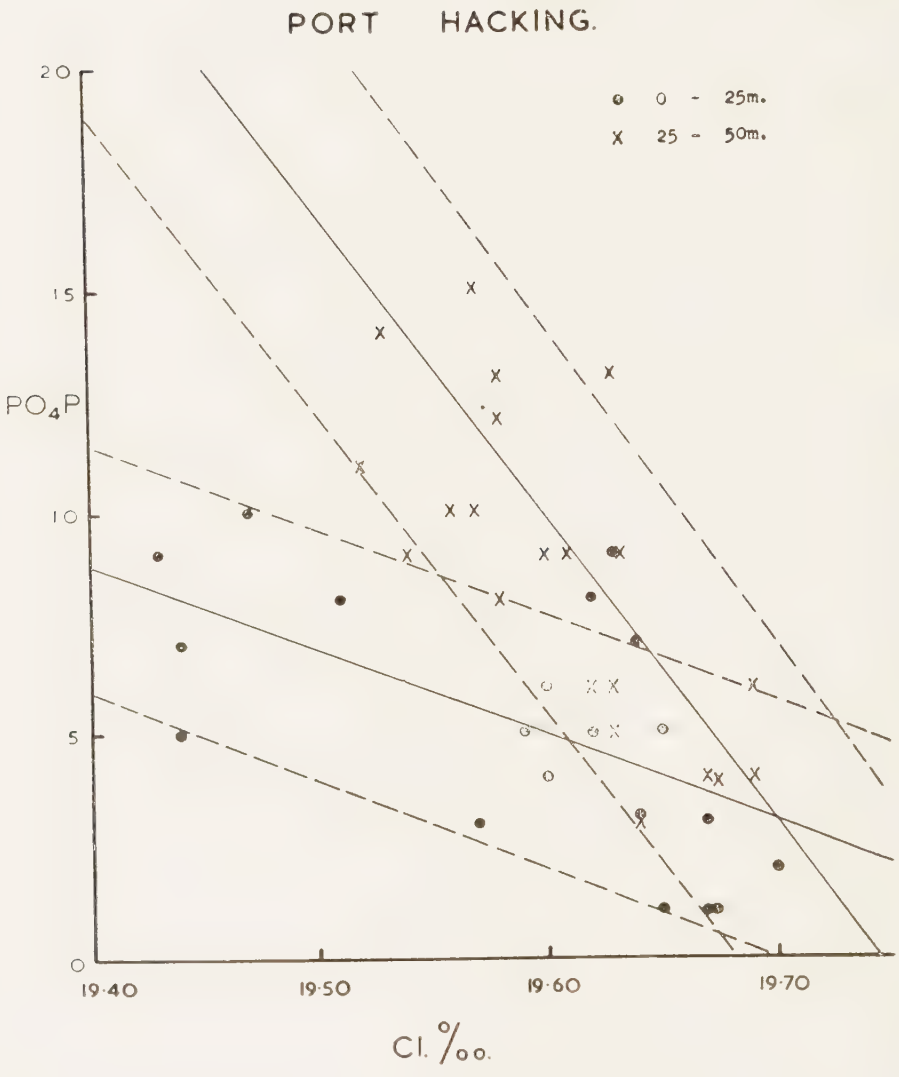

PORT HACKING.
o 0 - 25m.
x 25 - 50m.
20
15
10
5
0
PO4P
19·40
19·50
19·60
19·70
Cl. ‰.

FIGURE 9

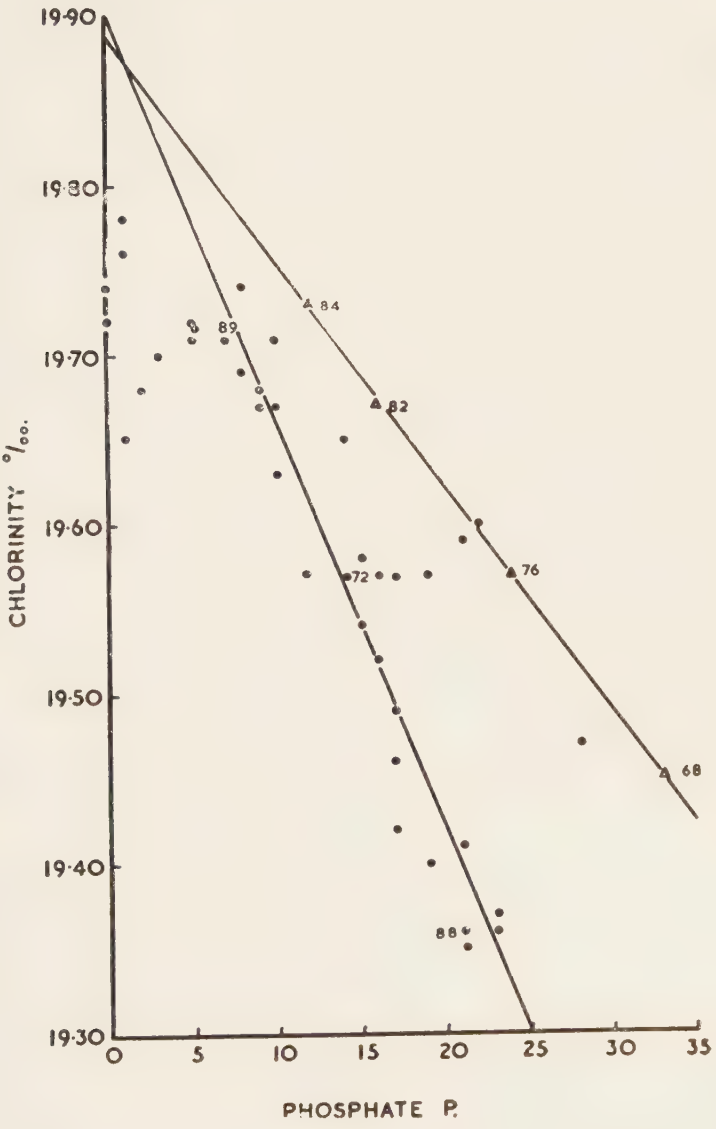

19·90
19·80
19·70
19·60
19·50
19·40
19·30
CHLORINITY °/₀₀.
0
5
10
15
20
25
30
35
PHOSPHATE P.
84
82
76
68
89
72
88

FIGURE 10

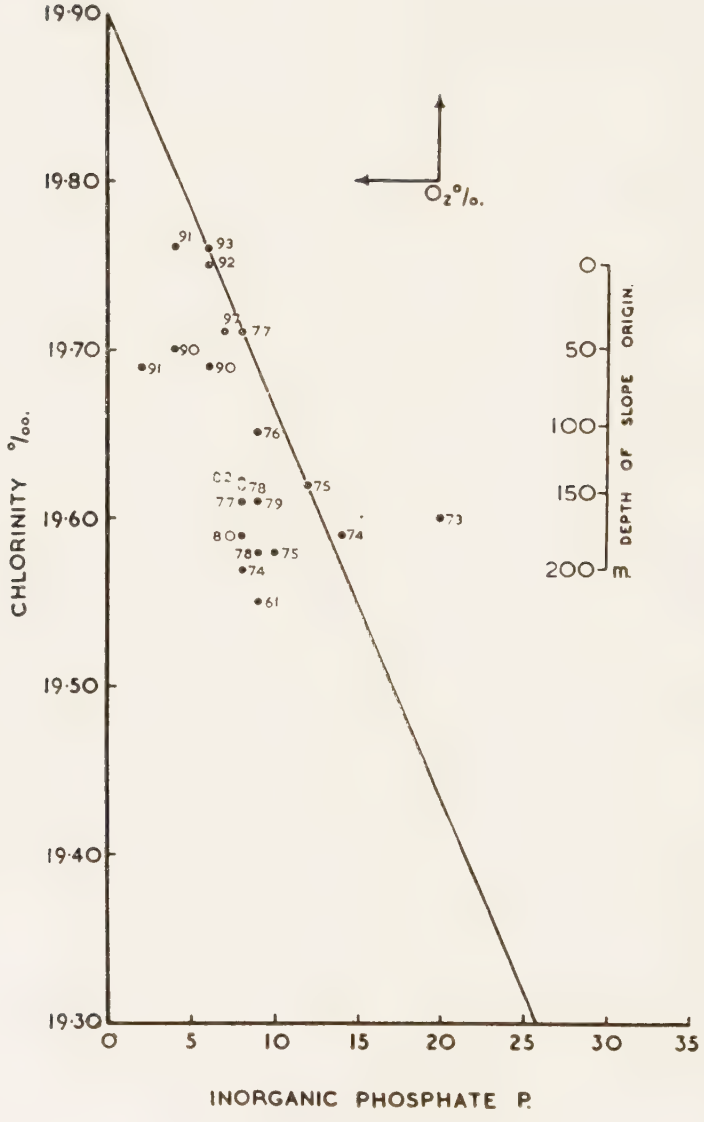

19·90
19·80
19·70
19·60
19·50
19·40
19·30
CHLORINITY °/₀₀.
0
5
10
15
20
25
30
35
INORGANIC PHOSPHATE P.
O₂°/₀.
0
50
100
150
200
m.
DEPTH OF SLOPE ORIGIN.
91
93
92
77
90
91
90
76
78
75
77
79
73
80
74
78
75
74
61

FIGURE 11

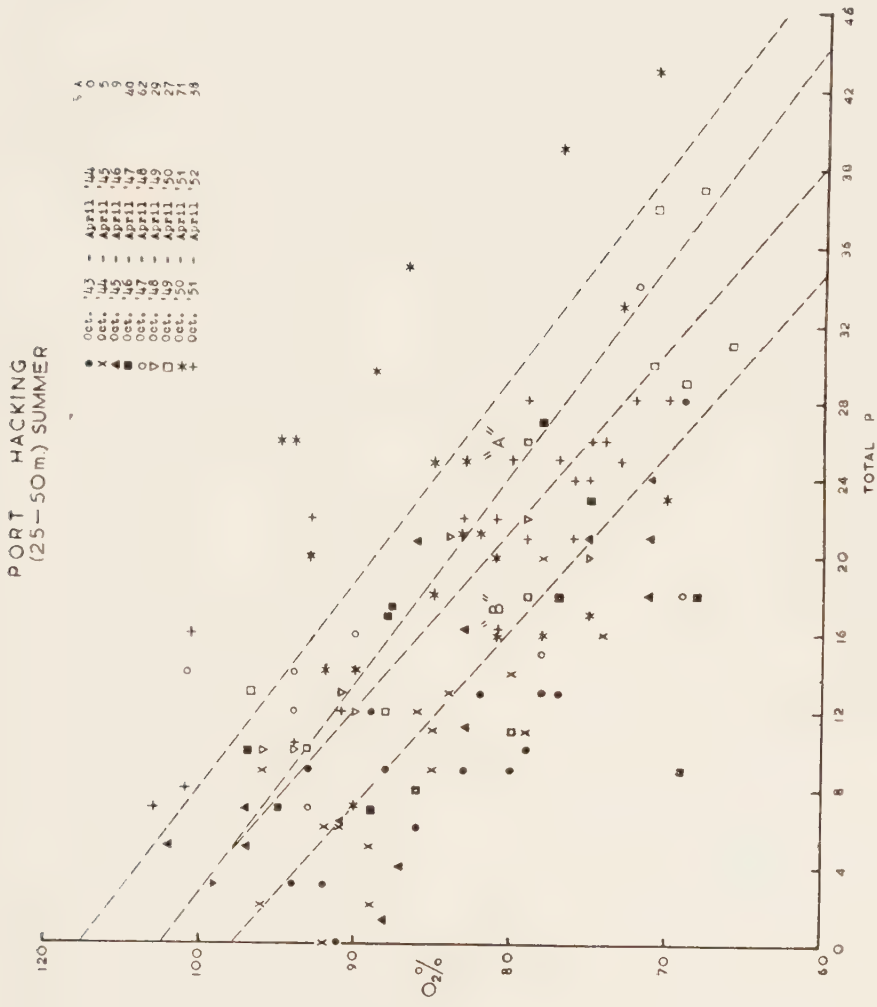

PORT HACKING
(25–50m.) SUMMER
Oct. '43 – April '44
Oct. '44 – April '45
Oct. '45 – April '46
Oct. '46 – April '47
Oct. '47 – April '48
Oct. '48 – April '49
Oct. '49 – April '50
Oct. '50 – April '51
Oct. '51 – April '52
A
5
9
40
62
29
27
71
39
"A"
"B"
O₂%
TOTAL P
120
100
90
80
70
60
0
4
8
12
16
20
24
28
32
36
38
42
46

FIGURE 12

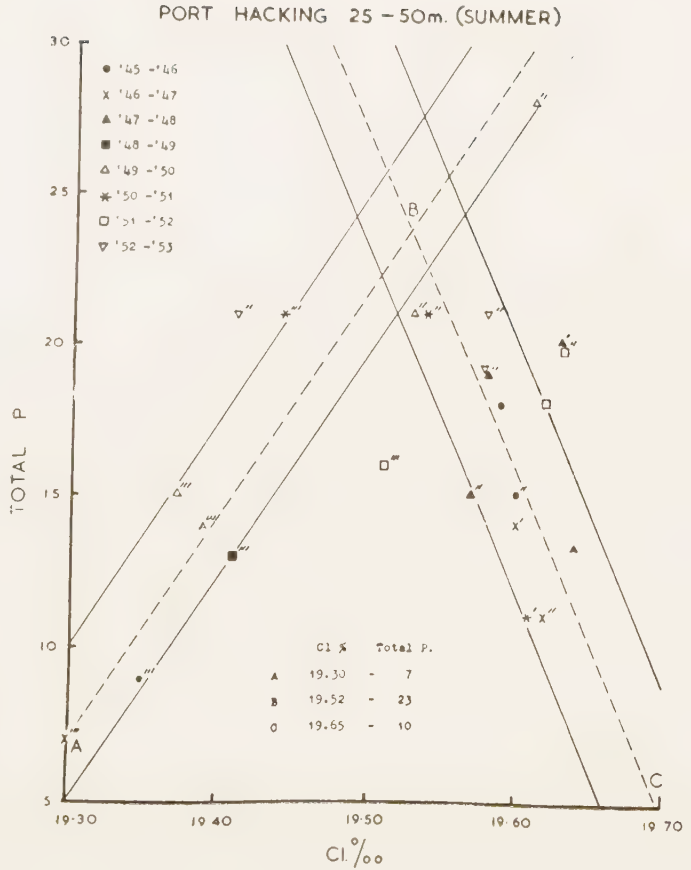


FIGURE 13

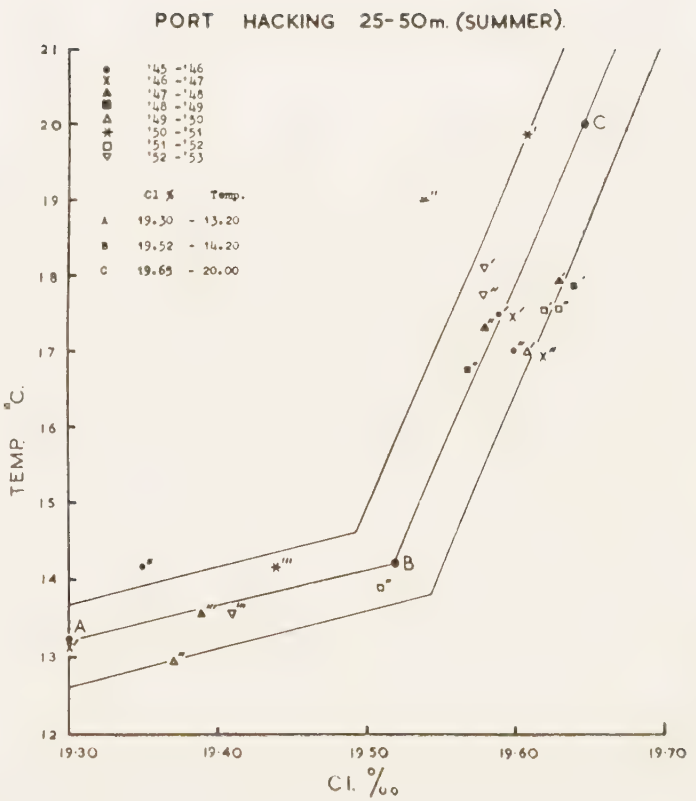


FIGURE 14

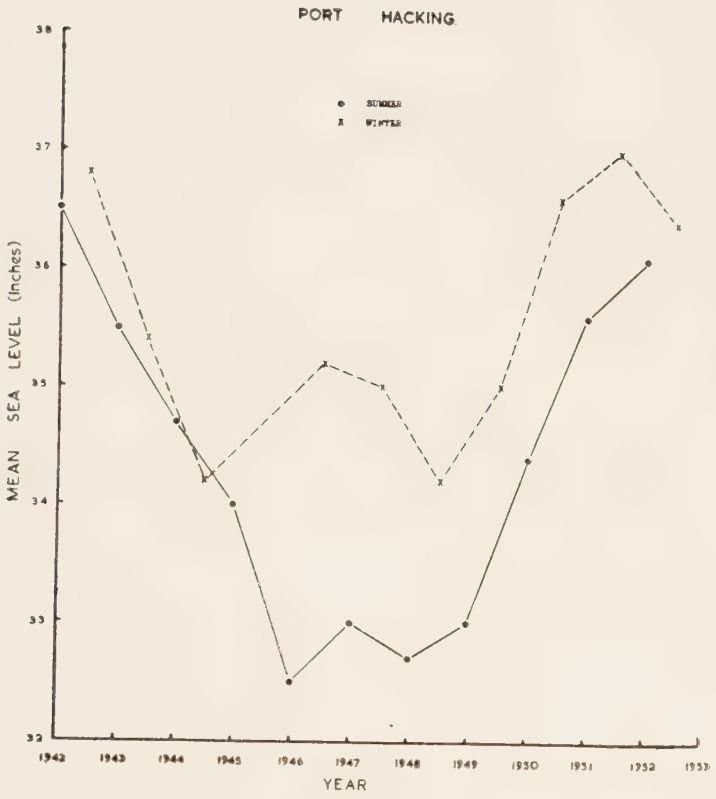

PORT HACKING
MEAN SEA LEVEL (inches)
38
37
36
35
34
33
32
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
YEAR

FIGURE 15

PORT HACKING (DECEMBER).
°C
19
18
17
16
15
14
13
(25–50m) TEMP
30
35
40
MEAN SEA LEVEL. (Inches)

FIGURE 16

RECENT DEVELOPMENTS IN TIDAL AND TIDAL CURRENT MEASUREMENTS *

U.S. Coast and Geodetic Survey

Current Measuring Equipment

During World War II, when a large part of its personnel and equipment had been transferred to the Armed Forces, the U.S. Coast and Geodetic Survey, in an effort to meet both military and civilian requirements, devised several new instruments and procedures. One of the most interesting of these is a radio current meter known as the Roberts Radio Current Meter after its designer Capt. E. B. Roberts, now Chief of the Division of Geophysics of the Bureau. The design includes both the meter and a special buoy to support the meter and house the radio transmitter.

As often happens after field trials, the first design of this equipment was found to have some features capable of being improved. These improvements have been embodied in a revised design known as Model II. However, Model I instruments are still being used with satisfactory results.

Equipment losses in congested harbor areas are likely to be high. Buoys with attached equipment sometimes disappear without trace and cannot be found by dragging. More often buoys are rammed by passing craft and set adrift. When found, if the meters are still attached, they are usually badly damaged. Frequently the meter suspension cable has been cut and all meters lost. Losses can be minimized to some extent by publication of operations in local and weekly Notices to Mariners. From time to time, it becomes necessary to replace equipment lost in operation, and successful bidders have found it desirable to make minor changes during construction. These have not changed the basic design, but unless made by the same manufacturer, parts are not always interchangeable.

The introduction of this meter represented such a radical change in standard methods for the determination of tidal current velocities that it was necessary to prepare a special operating manual for it. This manual has been revised periodically as improvements in equipment

* Contribution from the U.S. Coast and Geodetic Survey, Department of Commerce, Washington, D.C., U.S.A.
Presented by Capt. Andres O. Hizon, Director of the Bureau of Coast and Geodetic Survey, Republic of the Philippines.

and methods have occurred. The latest revision was made in early 1952. It will be revised again to include improved procedures developed during the 1952–53 seasons.

At present, research is underway toward improved designs for the transmitter and chronograph. Considerable work has been done on the design of a low-velocity highly sensitive meter for use on the bottom. Work is also in progress on an automatic recording system for these meters.

Field Methods

As indicated earlier, this meter is a wartime development, conceived as the solution of the problem of economical and rapid determination of surface current velocities of interest to marine navigators. The laborious and time-consuming methods involving the anchoring of vessels or barges on current stations could no longer be employed for lack of men and floating equipment. The Roberts Radio Current Meter provided an economical and relatively easy method for making current observations from surveying vessels engaged in hydrographic or other surveys within radio range of the buoy transmitters. The design of this equipment was based on the concept of single-meter operation. To permit satisfactory handling from small craft, weights were kept to a minimum. At first, normal operating procedure consisted of streaming a buoy with one meter attached—usually at some level 12 to 40 feet below the surface. At receiving stations, whether ashore or afloat, it is necessary to tune manually receivers to the frequency of each transmitter. This limits observations in radio-congested areas to six or seven meters for a single receiving station, as six or more clear, unobstructed frequency channels are difficult to find. Interruptions in transmission make records difficult to process—oftentimes worthless.

For marine transportation, surface current velocities are of paramount interest, and the Roberts Radio Current Meter was used at first to determine these. Because of its light weight it tends to lift in proportion to the strength of the current in velocities greater than about 2 knots. A tendency to sheer is noticeable in velocities of 3 knots. A leader was devised for attachment to the buoy anchor cable to obviate these tendencies. It was found desirable to use this leader regardless of the velocity because it causes the meter to pivot about a point of the anchor cable and produces more consistent results in current direction measurements.

Although the buoy, as designed, has a strong planing lift, it must be carefully streamed to insure satisfactory operation in strong currents. The lightest cable of adequate strength must be used. It has also been found desirable to attach buoy wings at the sides and bow.

The Roberts meter lends itself to economical operation for observation at one or two stations simultaneously with large-scale surveying activities in the same general area. Activities of this nature are usually carried on by vessels maintaining continuous radio watches. Radio personnel can monitor and receive the meter transmissions without greatly interrupting their normal routine. Since the advent of electronic ship-positioning methods, it is sometimes desirable to have electronic shore-station personnel receive meter returns from isolated current stations within range. This method is not as desirable as the ship receiving method unless electronic shore-station personnel are increased sufficiently to permit the usual "on the spot" tabulations.

For short-period observations, it has been found desirable on occasion to use the Roberts meter without the radio link. In practice a small vessel, or launch, is anchored on station and the meter hoisted in and out in the manner normally employed when using non-recording meters. The meter is connected electrically to a tape chronograph, but without the radio receiver and amplifier.

Revised Field Methods

Earlier methods have been revised and new components introduced which have made it possible to more than double the former rate of receiving. In the early days each meter required a separate radio frequency and transmitter. Monitoring, receiving, and tabulating records from six or seven transmitters were about all the receiving-station personnel could manage in one 30-minute observation period. Last year a timing device, known as the "Sequence Switch," was designed and developed in the Bureau. Since then it has become standard practice to suspend three meters from one buoy. By inserting the sequence switch in the meter circuits returns from each meter are coded and transmitted over one frequency. It is now possible to receive returns from 18 meters in one 30-minute period. This switch is illustrated and described briefly in the 1952 revised operating manual. An article concerning the switch appeared in the Surveying and Mapping News section of the 1952 September-October issue of the Military Engineer.

With the development of the three-meter suspension method it became necessary to discard the leaders. The added weight of meters and connections plus a 30- to 50-pound lead, or cast iron "sinker" below the meters prevents any great amount of lift in moderate velocities. Care must be exercised in attaching the two extra meters to prevent "twist" in electrical cables—otherwise they may not stream freely with the current. If this does occur, it can first be detected in the direction data, as, obviously any prolonged indication of directions normal to

channel axes must be erroneous. Multiple meter suspension was first used with 80-inch buoys. They do not have enough reserve buoyancy to carry the extra weight satisfactorily in strong currents. One-hundred-twenty-inch buoys are now being used with much better results. Their use also makes it possible to employ heavier "sinkers" and heavier ball-bearing swivels between meters.

For routine current work in the past, when velocities at levels other than surface were desired, observations were made at two-tenths, five-tenths, and eight-tenths of the depth at the station. In an effort to determine the behavior throughout the depth, observations have been made at varying intervals from surface to bottom. The larger number have been made at levels of 6 to 12 feet below the surface, at mid-depth, and at a minimum of about 3 feet above the bottom, irrespective of the rise and fall of the tide. The Woods Hole Oceanographic Institution has devised an experimental mounting for use in shoal water where velocities are desired at fixed levels within 1.5 to 3.0 feet from the bottom.

Equipment Availability and Cost

The Roberts Radio Current Meter and equipment is not patented. It is currently being used by several federal agencies and one or two oceanographic institutions. One English instrument maker has obtained a set of specifications and has, it is presumed, produced instruments for Admiralty use. Those used in the United States have been produced by three different "low-bidding" instrument makers, none of whom have produced them for general sales. The radio transmitters and sequence switches have been procured in much the same manner.

The major items of special equipment necessary to operate a current survey party using a launch and shore-based receiving station are listed below, with the approximate total cost.

1. Buoy, 120-inch	6	@	$760.00 —	$ 4,560.00
2. Roberts Radio Current Meter	18	@	550.00 —	10,000.00
3. Radio transmitter for buoy	6	@	400.00 —	2,400.00
4. Radio receiver for shore station	1	@	400.00 —	400.00
5. Chronograph, tape recording	1	@	675.00 —	675.00
6. Voice radio, for launch and shore station	2	@	750.00 —	1,500.00
7. Ground tackle, per buoy	6	@	200.00 —	1,200.00
8. Sequence switch	6	@	90.00 —	540.00
			Total	$21,275.00

From this it can be seen that the equipment required for one current party represents a modest investment.

Tide and Current Program

Early in 1951 the Bureau embarked on a tide and current program in domestic waters on a scale it had never before attempted. Several vessels were assigned this duty exclusively. Two of these were large enough to provide suitable berthing and working spaces for all personnel employed. Others were not, and it became necessary to establish self-contained receiving stations ashore. In protected waters the employment of the shore-station method permits the use of medium-sized launches suitably equipped to handle the buoys, but otherwise requiring few men. A shore station can be operated quite satisfactorily by nine men. One of these is the supervisor and relief and the other eight are divided into four watches of two men each. The launch and station combination makes for very economical operation, if or when overhead costs of larger vessel operation are considered.

Simultaneous observations of tides and currents have been undertaken as regular routine in this program. Normally, about one-third of the special tide stations in each area are established and operated for a period of 12 consecutive months. They are equipped with standard recording gages. The remainder are equipped with portable gages which are operated for 2 consecutive months. While the tides and currents are being observed, all tide station bench marks and tide staffs are interconnected by closed loops of first-order levels. This provides the means of relating the tide planes determined independently at each station. When the observations at the tide stations have been corrected to a 19-year mean through comparison with a reference station, the results show the variation of the different tide planes throughout the survey area as referred to a common datum. Also through combination of simultaneous tide observations and the interconnecting level lines, the pattern of gradient variation between stations throughout the tidal cycle can be established.

ON THE MINIMUM OXYGEN LAYER IN THE NORTH PACIFIC OCEAN

By Takeo Kawamoto
Kobe Marine Observatory, Japan

Oxygen in the sea is supplied by contact with the atmosphere and by photosynthesis. On the other hand, dissolved oxygen is consumed by the respiration of marine organisms and the reduction of bacterial action or the reducing agents of both inorganic or organic matters dissolved in water. Thus the oxygen contents in sea water are always affected by the reactions of general oxidation and reduction taking place in the sea. Besides the oxygen content in the sea are influenced by the mixing with other waters. Therefore, if there is no supply of oxygen in sea water, the dissolved oxygen will be diminished gradually. Then, if we observed a water mass which contained low oxygen value in the intermediate waters, we generally consider that the water mass had taken a long run and many times before reaching that region.

So when we discuss the property of the water mass or its movement in ocean, it is important and interesting to know the distribution of dissolved oxygen in sea waters. Though the causes of the variations in the dissolved oxygen content are not explained completely, but by tracing the distribution of poor oxygen layer in the ocean some aspects of the oceanic general circulation in the intermediate waters will be given.

We have much interest in the oxygen minimum layer observed at the depths between 400 and 1000 meters in the North Pacific Ocean. This paper is an attempt to obtain the general aspects of the general oceanic circulation in the intermediate waters in the North Pacific Ocean by the distribution of poor oxygen layer. Figures show the horizontal distribution of the dissolved oxygen at 250, 500 and 1000-meter layers, respectively.

These oceanographical data were obtained from the following reports:

The "Carnegie" in 1928, 1929.
The "Soyo Maru" in 1933, 1934, 1935.
The "E. W. Scripps" in 1938, 1939, 1940, 1941.
The U. S. S. "Bushnell" in 1939.
The "H. M. Smith" in 1950.
The "Tenyo Maru" in 1951.

From the figure (500-meter layer), we can recognise a remarkable poor oxygen region on the east side of the North Pacific Ocean. Especially off California, we can find even no oxygen at that layer; however, on the west side—Kuroshio region—the content being abundant comparatively. And in the Oyashio region the minimum layer is at shallower depth. This means that in the southern region off Kurile Islands there occurred upwelling of the intermediate water of the North Pacific Ocean.

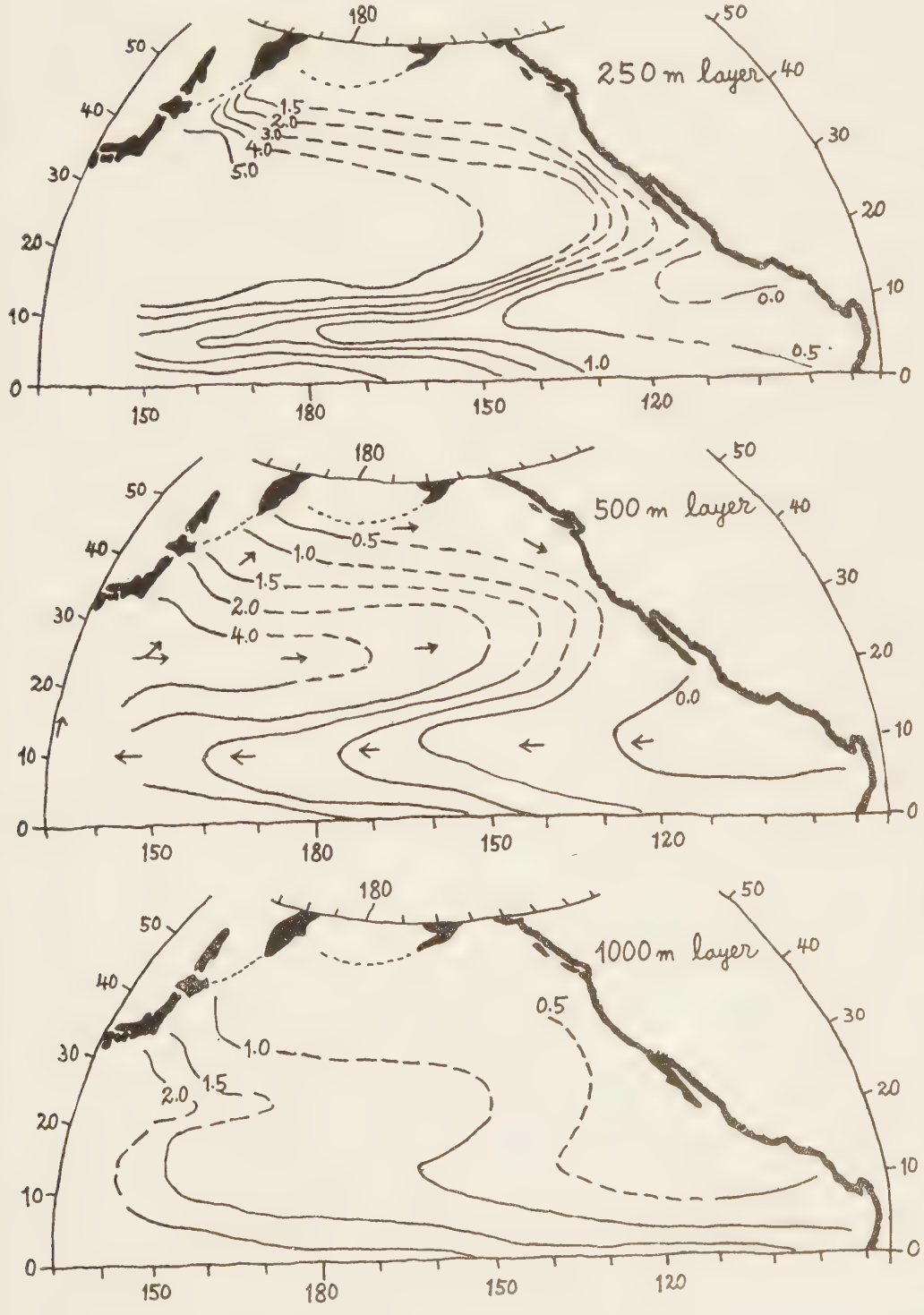
The writer will, in conclusion, show the general circulation of the intermediate water of the North Pacific Ocean as follows:

(1) In the region off California the intermediate water upwells and runs westward following the equatorial current.

(2) Before reaching the Kuroshio region it mixes with other waters along the route.

(3) A part of the above mentioned current takes the easterly course sinking to a lower layer.

(4) The other part of the current flows northward to the Kurile Islands region and runs eastward along Aleutian Islands to places off North America and California.


250 m layer
1.5
2.0
3.0
4.0
5.0
0.0
0.5
1.0
500 m layer
0.5
1.0
1.5
2.0
4.0
0.0
1000 m layer
0.5
1.0
1.5
2.0
180
150
120
50
40
30
20
10
0

A STUDY ON THE PROPERTY OF THE COASTAL WATER AROUND HACHIJO ISLANDS

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It is interesting to study how the property of the ocean water is affected by the presence of a tiny island in the far-off sea, and to what extent the coastal water of such an island is changed by land water pouring into the sea. Since the land water contains more nutrient matter than the offshore water, it may contribute more or less to the biological productivity around the island. Accordingly, a study of this problem will give also a basic knowledge for the coastal fisheries and the growth of sea weeds near the island.

For such a program, the chemical properties of the coastal surface water around Hachijo Island (33°05′N, 139°48′E) were studied in July, 1951, December, 1952, and in October, 1953.

Land waters of the island were also chemically investigated during the observation periods. In summer (from 13 to 28 July, 1951), the surface water temperature varied from 23.7°C to 27.4°C, pH of sea water averaged 8.3 and the mean chlorinity was 18.75‰. The concentrations of most of the nutrients in this season were so low that ammonia-N was less than 3μg atoms per liter, nitrite-N was also less than 0.05μg atoms per liter, and phosphate-P could be found only in traces. Only silicate-Si was present in an appreciable amount. The amount was about 10μg atoms per liter in the offshore water, but increased as the shore was approached until a quantity of 20 to 70μg atoms per liter was present. In winter (from 6 to 14 Dec., 1952), the water temperature of the surface was about 20°C and the chlorinity averaged 19.02‰, which was comparatively higher than in summer. The amounts of the nutrient salts were also larger. Nitrite-N and nitrate-N were contained from 0.05 to 0.70 and from 1 to 100μg atoms per liter respectively. Phosphate-P was from 0.05 to 4.0μg atoms per liter. Silicate-Si was from 10 to 70μg atoms per liter. The distribution patterns of these compounds around the island were like that of the chlorinity shown in Figure 1. As shown in Figure 1, the effect of the island on the ocean water was greater in the region from the eastern to the southern coast owing to the different amount of the outflowing land water as well as to the direction of the current. The effect of the ocean

current is seen clearly on the southern coast where the shadow of the current is formed.

The daily variations in the concentrations of some chemical substances were observed at a fixed point A in Figure 1.

It was found that the chlorinity change showed a good correlation with the tide, increasing and decreasing in the same direction as the elevation of the water level (Fig. 2). The relation between the silicate content and the chlorinity is almost linear as shown in Figure 3. Using these facts, we can calculate the mixing ratio of ocean water and land water. The result of calculation shows that the rate of mixing in the surface water at the distance of 100 m. from the coast line is about 25% in winter and the effect of land water seems to extend as far as to about 5 km. from the land.

The diurnal variation of the dissolved oxygen content is shown in Figure 4. It is maximum at about 14 h. and minimal in the early morning. Such a type of variation resembling somewhat that of air temperature may be regarded as a normal one as pointed out by one (Miyake [1]) of the present authors previously.

In summer the range of variation is greater than in winter, as the population of living matter and the intensity of the sunshine are larger in summer.

Since most of nutrient matter near the shore is supplied from the land, the chemical analysis of land water is also necessary.

There are a number of wells, small springs and a few streamlets in the island. These may be classified into two groups from a chemical point of view. The first group (A) of waters contains much chloride and nutrient matter while the second one (B) contains a considerably lesser amount.

It is interesting to note that the content of the silicate-Si in land water was comparatively larger in summer than in winter. In comparing the land water with regard to the nutrient matter, it is seen that the first group has a remarkably richer silicate and nitrate content than the second.

The average concentrations of both groups are shown in Table I.

TABLE I

	Amm.-N μg at/L	Nitrite-N μg at/L	Nitrate-N μg at/L	Phosphate-P μg at/L	Silicate-Si μg at/L	Chlorinity %
A	0.0	0.00	7.3	0.5	180	0.02
B	3.0	0.05	95.	1.7	190	0.60

[1] Y. Miyake: *Geophys. Mag.*, 16, (1948), 66-70.

FIG. 1.—The distribution of the chlorinity around Hachijo Islands, Dec., 1952.

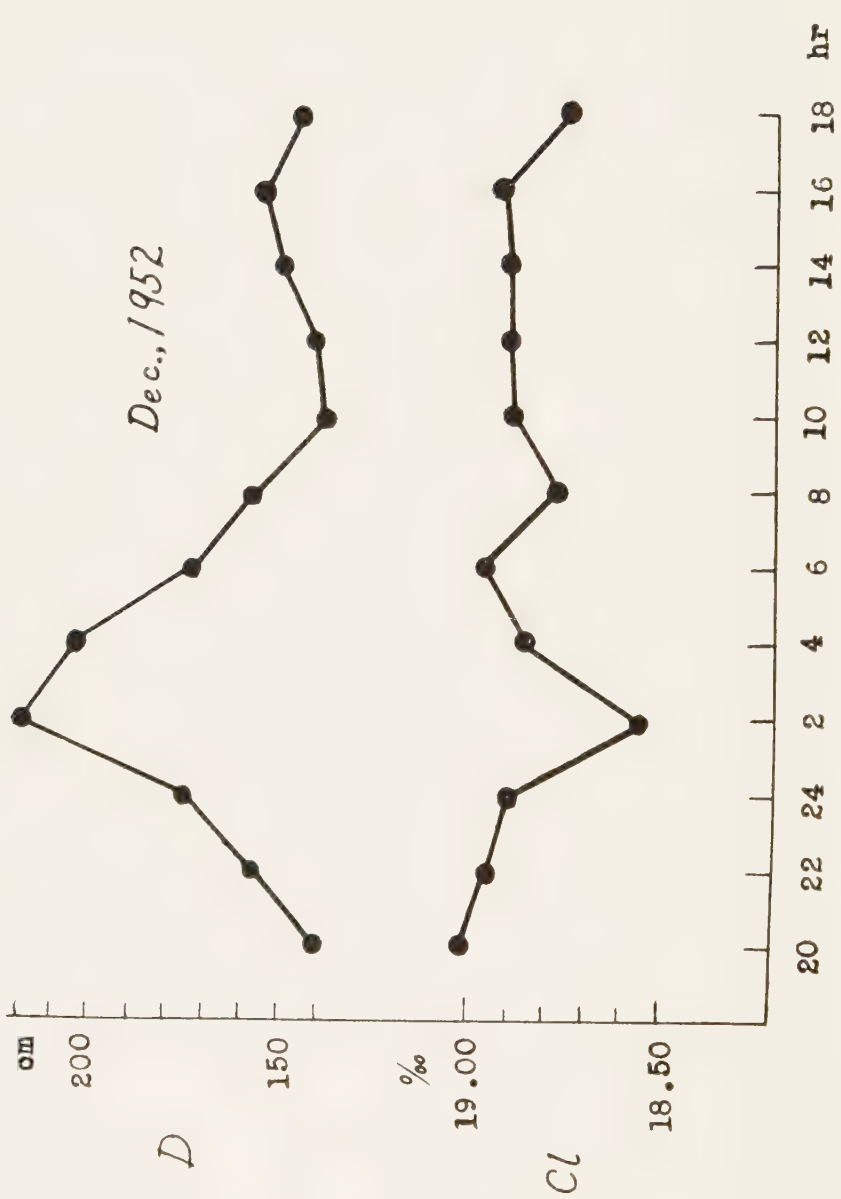

FIG. 2.—The relation between the chlorinity and the tide. D is a vertical distance to water surface from a jetty.

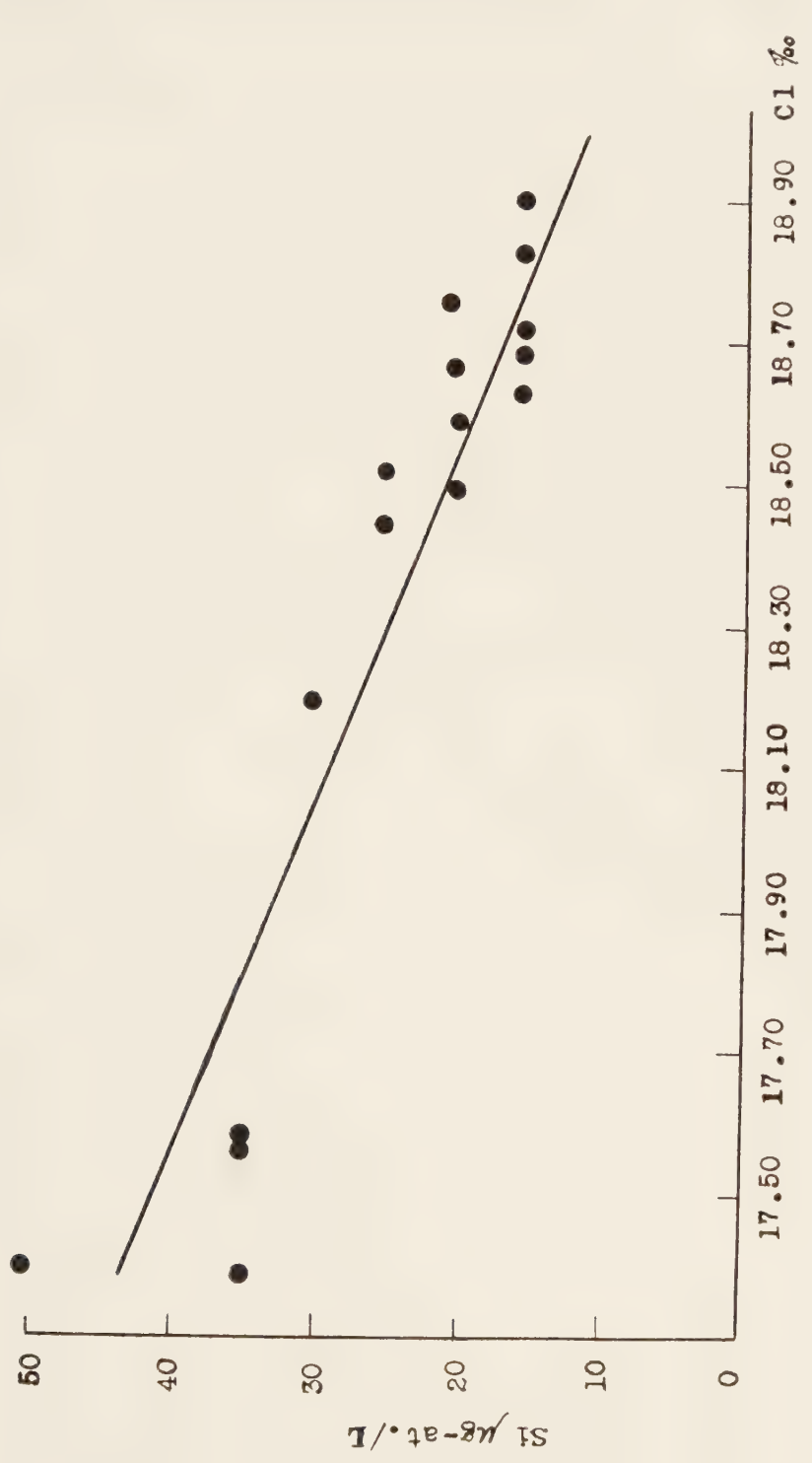

Fig. 3.—The relation between the amount of the silicate Si and the chlorinity.

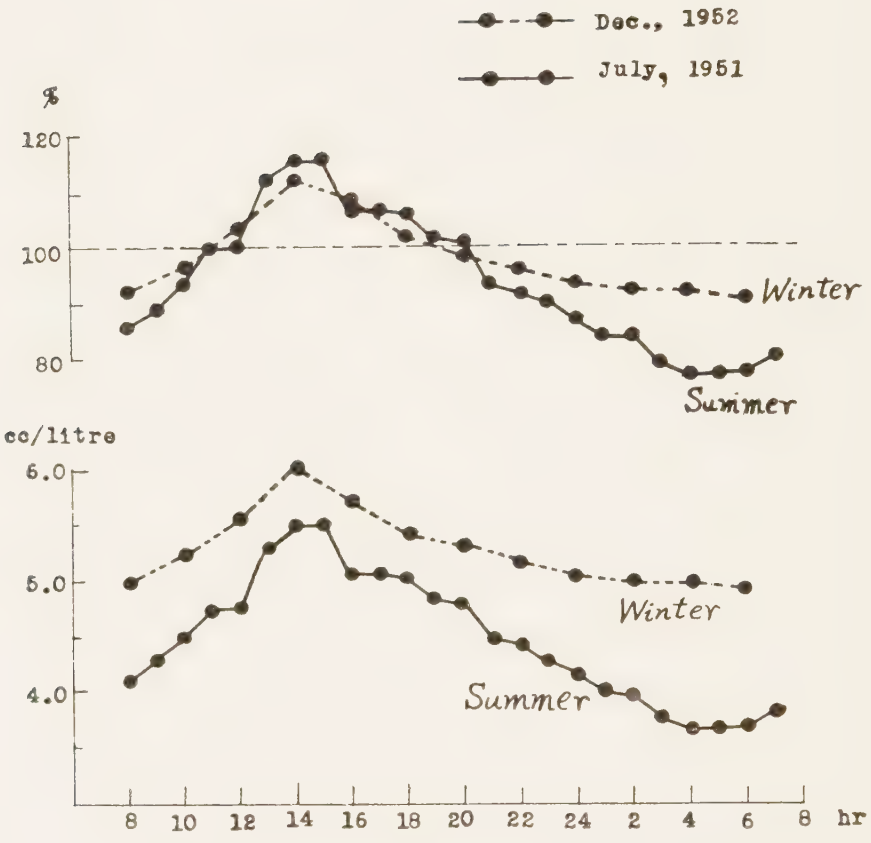

FIG. 4.—The diurnal variation of the dissolved oxygen.

ON THE OCEANOGRAPHICAL CONDITIONS OF THE SEA NEAR THE FIXED POINT, 153°E, 39°N, IN THE NORTH PACIFIC OCEAN

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1. Introduction

The variations of water temperature, chlorinity, etc. in deep layers of the ocean have not yet been made clear owing to the scarcity of continuous data of serial oceanographical observations taken at a fixed point for a long time. However, several years ago, ocean weather stations were set up, and serial oceanographical observations are being made without interruption.

In Japan, the first ocean weather station was established at the point 153°E, 39°N, in the North Pacific Ocean, in October 1947, and the second one at the point 135°E, 29°N, in June 1949. The former station is now named *"Extra,"* and the latter *"Tango."* The data of meteorological and oceanographical observations at these fixed points are published in *"The Results of Marine Meteorological and Oceanographical Observations,"* a quarterly bulletin of the Central Meteorological Observatory of Japan.

At these fixed points oceanographical observations are usually made from surface to a depth of about 1200 m. about 12–24 times a month, the main oceanographical elements observed being water temperature, chlorinity, and contents of oxygen and plankton. In the present paper the authors intend to report some results of investigation on the variations of water temperature and chlorinity in deep layers mainly, together with some other results, made from the data of observation at the fixed point *"Extra"* (Fig. 1).

2. Water Temperature

(a) *The annual variation of water temperature.* In the first place, the authors calculated the monthly mean water temperature of each layer. Figure 2 shows the variations thus obtained of water temperature of the layers 0 m. (surface), 25 m., 50 m., 100 m., 200 m., 300 m., 400 m., 500 m., 800 m., 1000 m. and 1500 m. From this figure we can see that the water temperature near the surface becomes minimum in February or March and maximum in August or September and that,

for the layers from 100 m. to 300 m. deep, the phases of change of water temperature are nearly coincident and the maximum temperatures generally appear between October and December. Moreover, the time of occurrence of the maximum temperature of each layer near the surface (0 m.–100 m. deep) tends to lag with increasing depth. For example, the maximum temperature of the surface layer appears in August, while that of the layer of 50 m. depth appears in October or November. This time-lag may be regarded as mainly due to the effect of eddy conductivity of sea water. If we assume that the said variation of water temperature near the surface is due to the effect of eddy conduction alone, the amplitude A_z of the annual variation of water temperature of a layer of depth z is expressed by the formula

$$A_z = A_0 e^{-\beta z}, \quad \beta = \sqrt{\frac{\pi}{\mu\tau}}, \tag{1}$$

where A_0 is the value of A_z for $z = 0$ (surface), μ the coefficient of eddy conductivity, and τ the period of variation (assumed sinusoidal), of the water temperature. Again, let ϕ be the phase lag of the variation of water temperature at the depth z; then

$$\phi = \beta z \Big/ \left[\frac{2\pi}{\tau}\right] = \tfrac{1}{2}\sqrt{\frac{\tau}{\pi}} \cdot \frac{z}{\sqrt{\mu}}. \tag{2}$$

If we calculate the value of μ by the formulae (1) and (2), using the data of oceanographical observations in 1948, we have the results as follows:

Layer	By formula (1)	By formula (2)
0 m.–50 m.	7.55	2.35
0 m.–100 m.	7.77	4.17

These values of μ are not so extravagant in the order of magnitude. However, as seen from the above results, the values of μ calculated by the two formulae (1) and (2) do not agree very well with each other. This is because we have neglected the effect of heat transfer other than that of eddy conduction.

(b) *Long periodic change of water temperature.* As seen from Figure 2, in the variation of water temperature of each layer, longer and shorter periodic changes other than the annual variation are also recognized. In order to eliminate the annual variation, if we apply the method of twelve-month moving average to these data, we have the results as shown in Figure 3.

From this figure we can see that the water temperature was rising from 1948 to 1951 and has been falling since the summer of 1951. As for the cause of this periodic variation, we cannot give any definite explanation for the present, but it seems that this variation is due to a long period change of water mass situation.

(c) *Short periodic change.* On the other hand, as mentioned above, in the variation of the water temperature of each layer, a short periodic variation is also recognized. This is especially the case for the layers 50 m., 100 m., 200 m. and 300 m. deep.

Now, the maxima and minima of temperature of the 100 m. layer as shown in Figure 2 were read off, and the time intervals between two maxima or minima were measured and are shown in the following table.

Time Interval of Temperature Maxima	Period (in Months)	3	4	5	
	Frequency	5	1	2	
Time Interval of Temperature Minima	Period (in Months)	2	3	4	7
	Frequency	1	4	3	2

(From 100 m. layer)

As is seen in this table, the short periodic change in question has a predominant period of 3 months. J. Fukuoka, one of the present authors, and T. Yusa have studied the variation of water temperature along the so-called "C-line" (Fig. 1) and it has been known that there exists a change of water temperature of about 3-month period in the sea adjacent to the Tohoku District (Northeastern Japan).

3. Chlorinity

Figure 4 shows the variations of chlorinity at different depths. From this figure we can see that the annual variation of chlorinity in the upper layers has a maximum in spring, which is due to the effect of continued evaporation, and a minimum in autumn, which is caused by heavy precipitation. Again, we can recognize that the chlorinity in the layers 50–100 m. deep, tends to become high from early summer to autumn. This could be due to the effect of the Kuroshio having high chlorinity. On the other hand, the chlorinity in the layers 200–500 m. deep is generally lower, which could be due to the effect of the Oyashio creeping current.

Further, if we look at the variation in chlorinity shown in Figure 4, we can recognize that the long periodic change of chlorinity is similar to that of water temperature, which is a fact worthy of being noted. Thus it seems that the long periodic change of chlorinity is also due to a long period change of water mass situation.

4. Colour of the Sea, Transparency and Plankton Volume

At the point *"Extra,"* the observations of colour of the sea and transparency have been performed since March 1948, and the collection of plankton since March 1950. In the following, we shall outline the result.

The annual variation of the colour of the sea is similar to that of the transparency, both with two maxima, one in summer and the other in winter, and two minima, occurring in spring and autumn. As to the seasonal variation of plankton volume, a very distinct maximum, a phenomenon of the so-called burst growth, occurs in spring and a less marked maximum in autumn, and a marked minimum appears in winter, and also, in a less degree, in early autumn. An experimental formula $D = 21.8V^{-0.25}$, where D represents transparency expressed in meters, and V the plankton volume in cc/m.^{3}, has been determined (Fig. 5), although there are involved somewhat unsatisfactory conditions such as the disregard of composition of plankton, the inequality between the values of transparency and the depth of the net haul, etc.

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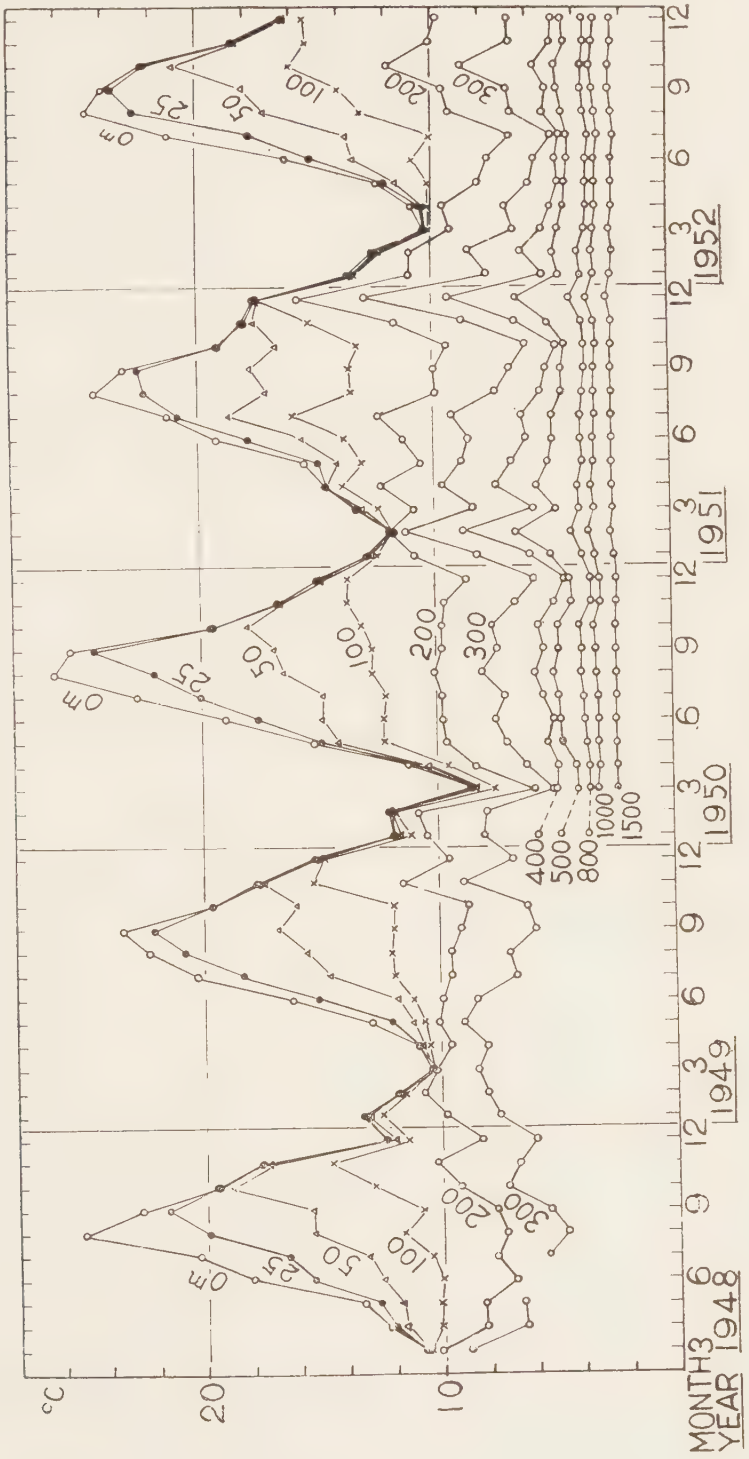
ILLUSTRATIONS

FIG. 1.—Map showing "C-line" and the fixed points "Extra" and "Tango."
FIG. 2.—Variation in water temperature at different depths.
FIG. 3.—The variation of the water temperature obtained by taking twelve-month moving average.
FIG. 4.—Variation in chlorinity at different depths.
FIG. 5.—Relation between transparency and plankton volume. The curve represents $D-21.8V^{-0.25}$.

45°N
40°
35°
30°
130°
135°
140°
145°
150°
155°E
JAPAN SEA
PACIFIC OCEAN
C-line
Pt. "Extra"
Pt. "Tango"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YEAR 1948 1949 1950 1951 1952
0m
25
50
100
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300
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500
800
1000
1500

FIGURE 2

Water Temperature (°C)
50m Layer
100m Layer
150m Layer
15
14
13
12
11
10
9
1948
1949
1950
1951
1952

FIGURE 3

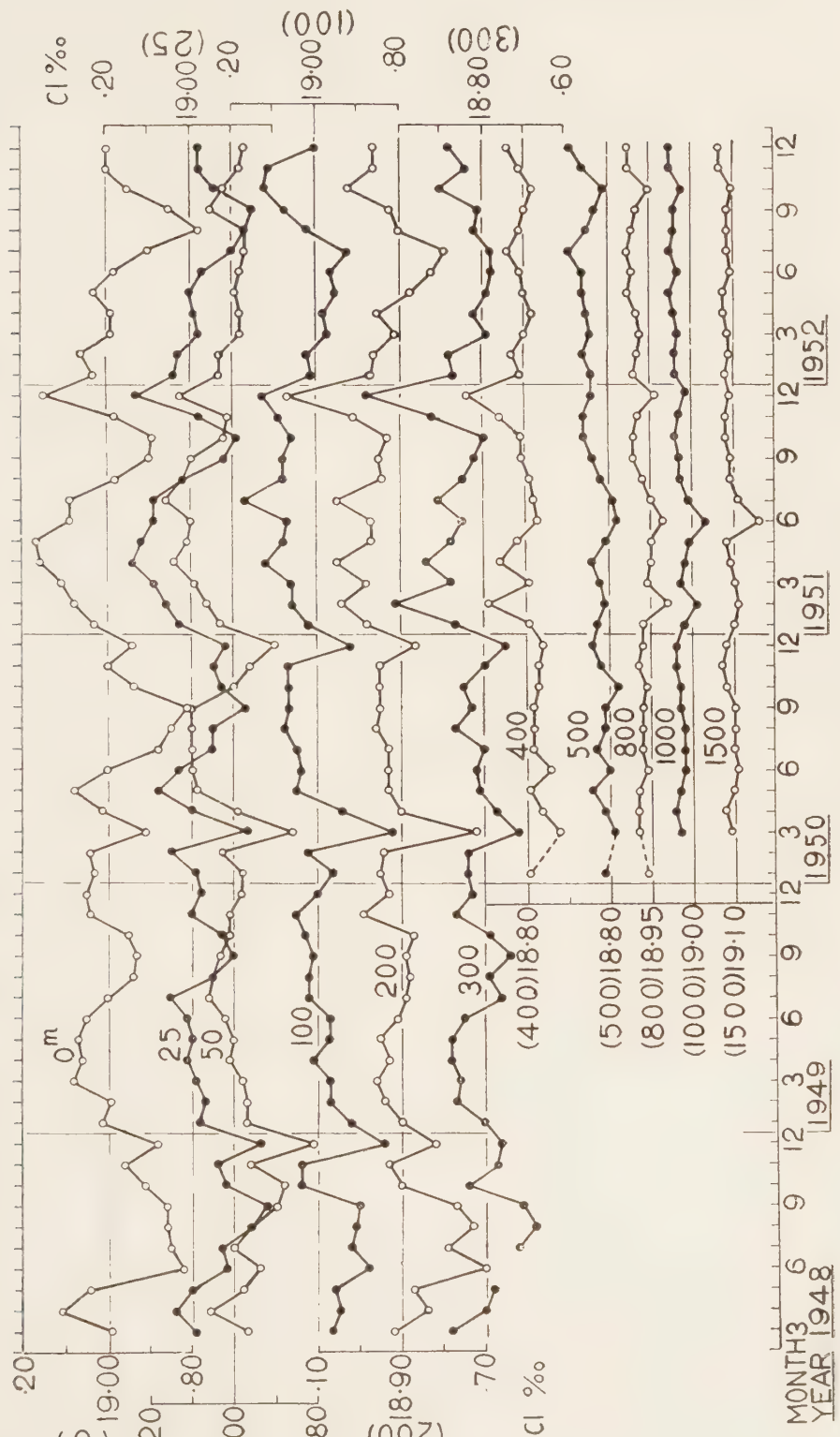
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FIGURE 4

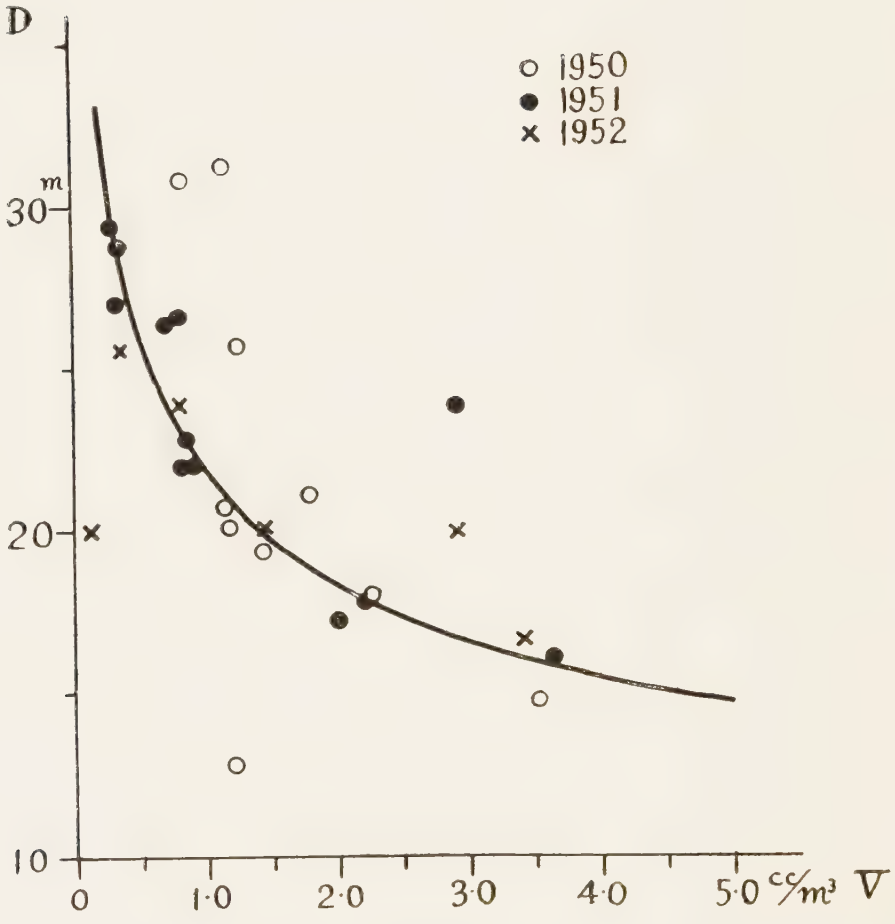

FIGURE 5

DISTRIBUTION OF COPPER AND ZINC IN SEA WATER (1)

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The contents of copper and zinc in the sea water have been repeatedly determined by many investigators. However, many of the data so far obtained are unfortunately unreliable, owing partly to defects in the methods and their application and partly to contamination from the metallic sampler used and often from insufficient care in handling collected samples.

Previously the author developed a procedure in which such defects and contamination can be avoided. He examined 21 samples of the surface waters from Tokyo Bay and Ise Bay (1).

Although these waters looked to be contaminated more or less by land drainage, their contents in copper and zinc were found far smaller than the values ever reported. Also it was noticed that their values decreased from the head of the bay towards its mouth, seemingly in parallel with contamination.

Naturally we are forced to expect that the far distant waters, free from the effect of land, will give smallest values and the copper value will drop probably below 1 μg/l.

Thus the study was extended along this line. First, the surface waters of the "Kuroshio" area were examined in May, 1951 on board No. 5 Kaiyo-maru, a surveying boat of the Hydrographic Office, Maritime Safety Agency, while at the second time the vertical distribution was determined in Sagami Bay and Suruga Bay in February, 1953, on board Umitaka-maru of the Tokyo University of Fisheries.

For collecting surface water a glass sampler was used, which had previously been thoroughly cleaned with special care; while for deep water sampling an Eckmann type sampler, coated with acrylic resin, was devised, taking into consideration that the trials by previous investigators, who used a metallic sampler, failed in getting a satisfactory result, due to probable contamination from the instrument. The determination was carried out by mixed-colour colorimetric titration with dithizone (2).

The results, given in Tables I and II, show that

1) The surface waters from Sagami Bay and Suruga Bay are richer in copper and zinc in comparison with those from the "Kuroshio" area, a fact indicating that the former are still affected by land drainage to any measurable extent.

2) The vertical distribution, given in Table II, shows that this contamination is limited to the surface and that the contents of the elements decrease in layers below.

3) Their contents, once decreased, rise up again from 200 m. or thereabout downwards. At the present stage of study it is difficult to decide what is the main factor determining the rise-up observed. However, at least it may be said that here setting free of these elements from dead organisms by decomposition in the course of falling down, contributes to the enrichment in the deeper waters, which is usually the case with other nutrient salts such as phosphate.

Unfortunately in the February cruise in 1953, the sampling from the "Kuroshio" area could not be done because of unfavourable conditions of the sea. The author is now planning, for the next step of study, an examination of samples from such an area as well as from other bays. Also the study will be extended to far deeper layers than ever examined and further to the seasonal variation of the elements. Efforts are also being made to improve the sampler by which the durability of acrylic resin coating is expected to increase.

Deepest thanks are due to Professor K. Sugawara for his guidance and to Dr. K. Suda, Director of Hydrographic Office, Maritime Safety Agency, and Professor M. Uda, the Tokyo University of Fisheries, by whose courtesy the author took advantage of participating in the surveying cruises. Also a sincerest condolence must be expressed to the late experts and crewmen of No. 5 Kaiyo-maru who missed, with the ship, the voyage for the exploration of Myojin Reef, which appeared last September because of undersea eruption, in recollecting the warmest help offered by them during my stay on board.

TABLE I

COPPER AND ZINC IN THE SURFACE WATERS FROM THE "KUROSHIO" AREA

LOCATION	DATE	Cu μg/l	Zn μg/l
St. 2, 34° 06′ N, 138° 09′ E	May 1, 1951	0.5	1.5
St. 3, 33° 40′ N, 138° 11′ E	May 2, 1951	0.6	1.3
St. 4, 33° 16.5′ N, 138° 13.5′ E	May 2, 1951	0.7	—

TABLE II

VERTICAL DISTRIBUTION OF COPPER AND ZINC

SAGAMI BAY Location: 35° 03.8′ N, 139° 21.8′ E Date: Feb. 12, 1953			SURUGA BAY Location: 35° 00′ N, 138° 39.1′ E Date: Feb. 15, 1953		
DEPTH m	Cu μg/l	Zn μg/l	DEPTH m	Cu μg/l	Zn μg/l
0	0.9	2.2	0	0.8	2.3
50	0.6	1.8	50	—	—
80	0.3	2.0	80	—	—
100	—	—	100	0.6	1.8
200	0.8	2.4	200	0.6	1.9
400	0.9	2.8	400	0.5	4.4
600	0.9	3.0	600	1.0	3.9
1,000	1.5	4.2	1,000	—	—

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ABNORMAL SUMMERS IN THE PERUVIAN COASTAL CURRENT

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The fact that the Peruvian Coast has a temperate and dry climate, although geographically situated in tropical latitude, is known since the Spanish conquest of Peru and northern Chile. The phenomenon of rainless years, especially rainless summers is due to the effects of the cool Peruvian Current which flows slowly along the greater part of the Chilean and almost the whole length of the Peruvian coasts, in the direction to the Equator. It was first explained by Alexander von Humboldt, who believed that this current was derived from the cold polar waters in the Antarctic. Modern investigation, however, proved that the low surface temperatures along that part of the West coast of South America are produced by "upwelling" of water from depths at more or less 130 m. below the surface. (Schott, 1931; Gunther, 1936).

In this zone, as in any other place, the most interesting phenomena are brought forth by anomalies which in the Peruvian Current are also observed from time to time. The basis of our knowledge regarding these abnormalities is laid by the description of the occurrences in 1891 and 1925, made by Schott in 1931. They have their origin in changes of the course of the Equatorial Countercurrent in combination with the displacement of the zone of convergence of the trade-winds of the northern and the southern hemisphere, and of the situation of the barometric low-pressure-area. Although very little is known regarding the mechanism which originates these changes, we are well informed of the effects it has on the Peruvian Coast. Thunderstorms and heavy rainfalls accompany the change of the hydrographic conditions as far as about 9°S. Further south the coastal plain and the western slopes of the Andes are soaked by rains producing great landslides and destruction of arable soil. Together with such meteorological and hydrographic anomalies goes a deep change in the ecologic conditions in the Peruvian Current which leads eventually to a complete destruction of the habitual life in the current.

The last of these great catastrophes occurred in 1925, and since then the system of the current and life depending upon its normal con-

ditions were repeatedly subject to invasions of the Equatorial Countercurrent with some of its consequences but never in such a degree as reported for the summer of 1925. The author presented to the Sixth Pacific Science Congress in 1939 a paper regarding the hydrographic anomalies observed in that same year and by coincidence he wishes to relate to the same Congress to be held in November 1953 about other, and perhaps even greater, disturbances of the normal conditions in the summer of 1953.

It must be said that nearly all reports contained in the oceanographic literature about destructive biological changes in the Peruvian Current are extremely exaggerated and generalize the extraordinary events which have been observed only twice during the last 62 years. Some abnormal situations, marked by the emigration of the guano-birds, are recorded for November-December 1912, March 1917, March and June 1923, but only for 1923 is the death in greater extension of fishes mentioned (Lavalle 1917, 1924). Later perturbances occurred in 1932, 1939, 1941, 1951 and the last one just recently in 1953, this, however, without any biological consequences. These are characterized by the emigration of almost all or at least an appreciable part of the guano-birds which occupy the small islands off the Peruvian shores. Nothing has been heard or seen since 1938 of a widespread mortality of fish, except some rare occurrences when fishes still alive were washed ashore (1941), perhaps poisoned or suffocated by lack of oxygen. However, oceanographic perturbances have taken place in all these years and in a lesser degree also in 1949. If it were not for the behavior of the guano-birds, which are carefully watched in view of their importance as producers of guano, one source of Peru's great wealth, the abnormal conditions in the sea would not be noticed. Abnormalities can only be detected by careful hydrographic observations.

It is not the intention of this paper to enter into details about the biological changes which take place in years of greater hydrographic perturbances, but only to show the abnormal features of the summer of 1953 in comparison with those of some other years, and to discuss some hydrographic phenomena connected with these disturbances.

All the data used for the original charts reproduced herewith are based in their greater part on observations made by the author on board ships of the Guano-Company (Compañía Administradora del Guano, Lima), in sailing ships in 1939 and 1941 and complemented by data obtained from merchant vessels navigating along the Peruvian Coast. The data collected are kept in special oceanographic archives of that same Company. It must be stated here that the great merit of the Guano Company, besides the absolute and well planned protection

given to the guano-birds, consists since the first years of its existence in having initiated and supported scientific investigations related not only to the birds, but also to the whole ecological and hydrological complex in which they live and upon which depends their well-being.

Selected from the representation of abnormal situations are the years 1939, 1941 and 1953. Maps concerning the year 1947 which might be looked at as an abnormal year have been inserted. It has been included only because it shows for the month of March an ample review of the conditions in the outer limits of the Gulf of Guayaquil. All available data have been sampled and averaged in squares of half a degree of geographical latitude and half a degree of geographical longitude, and according to the averages thus obtained isotherms were traced. For all the above mentioned years drafted charts are presented for the months of March and April, although in some cases maps referring to February would already show some major anomalies; these, however, have been left out, in order to avoid undue length of this paper.

The number of observations on which these maps are based is as follows:

1939	March	131	April	157
1941	"	619	"	293
1947	"	855	"	681
1953	"	380	"	737

An isothermic chart for normal conditions in the Peruvian Coastal Current (Fig. 1) shows the isotherms running parallel with the continental coast, whilst abnormal situations originated by an invasion of the Equatorial Countercurrent in 1891 and 1925 are represented by the almost perpendicular course of the isotherms to the shoreline (Figs. 2 and 3). On the other hand, both of these maps show along the whole Peruvian littoral as far south as Callao (Fig. 2) or a little further than 10° S, temperatures of 26°C, although perhaps in the immediate vicinity of the coast, lower temperatures may have been present.

None of our charts (Figs. 4–7) shows something similar, running all the isotherms more or less parallel to the coast. The highest inshore temperatures have been observed in 1941, but the highest temperatures in the outer part of the Gulf of Guayaquil and also off the southernmost part of Peru were observed in 1953. March 1939 (Fig. 4) shows the nearest approach of a 27° isotherm to the Peruvian coast at 8°S and that of the 26° isotherm at 10°S. The extension of the hydrographic perturbance brought forth by the warm waters which evidently came from the north is easily seen by comparing the maps for March 1939, 1941 and 1953 (Figs. 4, 5 and 7), with March 1917 (Fig. 6), where

the outer limits of the Gulf of Guayaquil are completely under the influence of the very far northward reaching outlet of the Peruvian Current, whilst only the inner parts of the Gulf indicate higher temperatures belonging to waters which may be able at any moment to form the "real Niño Current" (Schweigger, 1945).

The maps for April (Figs. 8–11) contrast strongly with those for March. It is evident, in all of them, the depression of the sea-surface-temperatures as compared with March. Only in 1953 (Fig. 11) the 26° isotherm was observed nearer to shore than in March of the same year. The diminution of the surface temperatures is especially visible in the southernmost part of the Peruvian littoral and also in the Gulf of Guayaquil where all temperatures are reduced. Unfortunately, data are missing for April 1941 north of 9°S and south of 14°30'S, and it is just this year which seems to have shown the greatest anomaly of all the years since 1925. The extended voyage of the author to the region W of Pisco (12°–14°S) allowed him to trace the isotherms over a great area in the open sea, and it must be deduced from the distribution of the hourly observed surface-temperatures that in April 1941 the isotherms for 26°, 25° and 24°C had a course nearly perpendicular to the continental coast, at least from a certain distance on, being space left for lower temperatures along the Peruvian shore.

Three parts of the coast deserve our greatest interest: The Gulf of Guayaquil, the area included by the latitudes 9° and 10°S and the region between Atico-Ilo-Arica. The position of the isotherms in the Gulf of Guayaquil for March and April 1953 (Figs. 7 & 11) leaves no room to doubt that the high sea temperatures are derived from the NW, which can only mean an advance of the Equatorial Countercurrent, corroborated also by low salinities. In March 1939, as in March and April 1947 (Figs. 4, 6 and 10), the highest temperatures in this zone belong without doubt to the interior parts of the Gulf and extend from there to the W and SW. The conditions in April 1939 and in March 1941 (Figs. 8 and 9) cannot be determined satisfactorily in view that observations are available only for one route of navigation, although in March 1941 the highest sea temperature (27.5°C) was observed E of 81°W whilst in the half-degree-square just W of that meridian the surface temperature was found half a degree lower (27.0°C). The warm waters south of Cabo Blanco, and especially those southwest of Aguja Point, must be brought in connection with the open ocean, but not with certainty with the Equatorial Countercurrent, although in March 1941 very low salinity was observed between 8° and 6°30'S which induced one to believe that these waters had come from the Equatorial Countercurrent. But as these titrations of salinity had to

be made without control by standard-seawater, their true oceanographic value cannot be emphasized.

The revision of the charts regarding the region between 3° and 4°S leads to distinguish two different movements of warm water north, northwest and northeast of Cabo Blanco. Figures 4, 6, 10 and perhaps also Figure 5 show the expansion of warm waters from the inner part of the Gulf of Guayaquil. These surround frequently Cabo Blanco in a southerly direction and are then identifiable as far as 5°S, sometimes even further, to the south by higher temperatures, lower salinity and a different fauna (especially fishes) (Schweigger, 1943, 1945), but are without any climatic influence on the northern territories of Peru (Zorell 1928). Such a southerly flow of warm water is not only produced in summer months, it may happen in any month of the year.

Contrasting with these features are the maps for 1953 (Figs. 7 and 11) in which the warm water without any doubt is coming from the northwest. Such a direction of the flow is also indicated in Figure 2 (1891) and this is evidently also the meaning of the charts in Figure 3 (1925). Such a situation seems to be characteristic for the major disturbances in the outer parts of the Gulf of Guayaquil with the consequent production of climatic abnormalities at least in the northern parts of Peru.

A rapid fall of surface temperatures near Cabo Blanco and south of it indicates the presence of warm water derived from the interior of the Gulf of Guayaquil, whilst on the other side high inshore temperatures between Cabo Blanco and Aguja Point are connected with the inrush of warm water from the northwest, which comes from the open South Pacific Ocean or the Equatorial Countercurrent. Following this differentiation, it seems possible to attribute the high temperatures between 4° and 6°S shown for March 1941 (Fig. 5) to the influence from northwestern areas.

The second interesting feature in these maps is the pressure of warm water against the coastline between 9° and 10° and sometimes 11°S. This is most impressively represented in April 1953 (Fig. 11) but can be deduced to a greater or lesser extent from many of our maps and even so from Figure 3. An elevation of the surface temperatures at the south or the southwest of Chimbote is observed almost regularly throughout the year. The zone of warm water seems to be connected with a countercurrent which spreads out south and southeastward in coastal areas and is known by all navigators by its accelerating effect when sailing from Huarmey on a southerly course. Repeated observations have shown that the water entering there is of higher salinity than the normal inshore water, so that it seems justified to consider

the space S and SW of Chimbote, or W of Huarmey as one of the most susceptible zones for the entrance of warm oceanic waters with the tendency to spread out, not only in the direction of the flow of the Peruvian Current, but also in the opposite direction (sometimes with a wide-reaching influence on fisheries).

The presence of warm water in this part near the coast is also shown in the isophletic diagram published by Schott (1931) for the abnormal period of March 1925. The diagram reveals that the ships passing between 8° and 10°S registered in almost all voyages higher temperatures than those observed further north. This held true in April 1953 (Fig. 11) when temperatures of 26.5°C west of Chimbote were higher than the temperature found about 3 days later off Cabo Blanco. The possible heating influence of this zone upon the southward warm water flow, recorded in 1925, has been mentioned by the author in an earlier paper (Schweigger, 1949).

According to his own repeated experiences and the frequent observations made by merchant ships in all months of the year in this zone, the author came to the conclusion that the advance of the warm waters must be directed to the northeast as it is also suggested by Figures 4, 6 and 11. But nearly every one of our maps referring to summer months shows at the NW or at the west of Chimbote the curvature of the isotherms, especially of those for 27° and 26° and 25° with its axis directed to the SE, as if the warm water were rushing in from NW (see also Fig. 3 for comparison). This, however, is a problem whose discussion may be taken up later.

Perhaps more interesting still is the region in the extreme south of the Peruvian littoral which could be circumscribed as situated between Atico-Ilo-Arica and Iquique (see Fig. 12). The center of this zone seems to be the area off Ilo, from where the warm water makes its appearance and then disperses partly in direction N and NW (together with the Current) and partly to the southeast, turning outside Arica southward and making itself discernible as far as the latitude of Iquique in the form of a "tongue" of warm water keeping always at a certain distance off shore.

The author has been able to corroborate such a distribution of surface-temperatures in different opportunities travelling between Iquique and Peruvian ports mostly during winter months, when temperatures in this "tongue" were not so high to make it difficult to correlate them with other temperatures in more northerly zones of the Peruvian coast. But although this paper is really not so much concerned with the southerly flow of warm water in northern Chile, it may not be superfluous to illustrate such a situation by means of Figure 12, which at

the same time serves to underline the difficulty to understand the movements which bring these high temperatures to the zone between Ilo and Arica.

Figure 12 differs from the other charts in so far as it combines the observations of only two ships which sailed the whole Peruvian and part of the Chilean coast from Talara to Iquique during 20 days (16th of February to 8th of March 1948). The map contains also some earlier observations made by the northbound vessel off Cabo Blanco and in the interior of the Gulf of Guayaquil (8/9 of February) in order to represent a typical distribution of high sea temperatures in the zone of Cabo Blanco and northeast of it. Both these ships passed, according to a previous understanding, a zone situated 80–90 miles W of Pisco in order to obtain information about the conditions there at this time of the year. The comparison between the observations registered W of the northern part of the Peruvian shore (4°–6°S) and those made while sailing from Talara to Callao, suggests that a very strong invasion of warm water must have taken place in the 8 days between 9th and 17th of February which shoved the 24° isotherm more or less 90 miles to the SE. The most interesting feature of Figure 12 is the appearance of the temperature of 26.2°C off Arica (27th of February) whilst neither the first boat passing the zone W of Pisco (16th of February) nor the second one (7th of March) observed more than 25.3°C. Between these dates the warm water off Pisco had expanded, but it cannot be said if its extension found on the 7th of March was already diminished after having reached a culmination in the foregone days or if the expansion was a steady one during all the time. The high temperatures off Arica place before us the following problem: If they are connected and how far with the invasion of warm water in 6°–7°S, or the other one in 13°–14°S. That the temperature registered off Arica was a recent one, can be concluded from the fact that data obtained in the same half-degree-squares before and after the sailing from Iquique prove that the water was cooler between the 22nd and 24th than between the 26th and 27th of February.

It seems undeniable that such a "tongue" of warm water as shown in Figure 12 and which is also confirmed by a series of maps in a recent paper by Bini (1952) must have its origin in the region situated between Ilo and Arica. It seems difficult, however, to trace back the warm water and connect it with waters still warmer in further northern parts of the Ocean. It seems possible to draw the isotherms for 25°C in 17° and 18°S (Figs. 4, 7 and 12) in such a manner that they join the isotherms for the same temperatures at the N or NW of Callao. The author does not feel that such a course might be considered correct.

April 1941 (Fig. 9) shows for example that the isotherms for 26°, 25° and 24° at the peak of the invasion of the warm waters must have had a direction from approximately WSW–ENE. It seems improbable that they turn further offshore to the direction NW–ES in order to show up again off Ilo and Arica. Should we believe that the high temperatures reach this region as consequence of the invasion of warm waters from the NW and are curtailed when the invasion reaches the culminating point (isotherms stressed out WSW–ENE), or is there a steady flux of new warm water from another source? We must also take in account that the elevation of temperature off Mollendo-Arica is practically a constant phenomenon, although the amplitude of the variation of temperature is less in winter time.

On the other hand, according to the map published by Schott and Schu, (quoted from Gunther, 1936), surface temperatures of 22°–20° are traced as belonging to the latitudes 17°–20°S in the open ocean far away from the Continental Coast, deflected, however, some 1200 miles offshore in the NE direction, by the northerly movement of the waters along the coast of South America. Their position during March 1891 and 1925, makes us look with awe at the overwhelming forces of the Equatorial Countercurrent, which stemmed back these isotherms to their position in the outer ocean over an area of nearly 1200 miles wide in those latitudes. We see now that none of the perturbances of 1939, 1941 and 1953 can be compared with the catastrophes of 1891 and 1925, which for their part restituted for a short time the hydrographical and meteorological situation corresponding to the geographical latitudes of the coast involved, where the cool water of the Peruvian Current has created a thermic anomaly of such a magnitude.

None of our maps entitles us to draw the isotherms in the zone off Ilo-Arica-Iquique in the same manner as for 1891 and 1925. The isotherm for 25° situated there has therefore been left open without suggesting any solution of our problem.

Nevertheless, it might be possible to look for an explanation of this phenomenon off Ilo and Arica, and the other one, created by the warm water off Chimbote, in the hypothesis of Gunther (1936). He supposes the existence of two different countercurrents, "warm wedges", off the Peruvian Coast which flow in a southeasterly direction, one starting more or less off Aguja Point and reaching as far as the latitude of Callao and the other one coming out of a region WSW of Pisco and entering near the coast just off the bay of Arica. Both these countercurrents transport, according to the view of Gunther, warm water from the NW to the SE. The author of this paper has objected (1943) against the existence of these two "warm wedges", because Gunther cor-

relates observations which are too far apart, not only in space but also in time by many days and even by weeks. This is a procedure which does not seem advisable in a current system exposed to so many and so sudden changes, as Gunther himself had to admit. During all his numerous voyages in the Peruvian Current, the author only once came across a situation which could induce him to accept the idea of Gunther (1943, p. 242).

On the other hand the fact must not be overlooked that Gunther made his investigations in the Peruvian Current in the winter of 1931 between the warm summer of that same year and the still warmer one of the year 1932, so that the countercurrents appeared to be the result of some unstable situation in the Current, an idea which might be supported by our maps which show that in all of the abnormal years the warm temperatures advanced more or less in the same sense as proposed by Gunther (the line of the least resistance?). The northerly axis of these "warm wedges" runs parallel with the axis of the bend of the isotherms for the high temperatures which according to our maps seem to advance in direction to Chimbote, Huarmey or even Callao; there is only a slight difference insofar as the main axis of Gunthers countercurrent lies a bit further to the south and west than ours. It should, however, be taken into account that Gunther's observations have been made during winter months, whilst our figures are all referring to summer time.

The southerly countercurrent constructed by Gunther does not coincide, as well as the northerly one does, with the apparent movements of warm water to the SE; but it would be possible to accept this theory of Gunther's as a working hypothesis. The author must repeat that the Peruvian reconnaissance could not yet be widened so far out at sea as to prove or deny for any time of the year the existence of such countercurrents, and it must be borne in mind that the Guano Company has to make great sacrifices for all the research work done. The voyages made by the author took place during the routine travelling of the ships of the Guano Company, which allowed their captains, with a fine understanding of the scientific requirements, to take different courses from the normal ones, according to the wishes of the author in order to make hydrographic investigations, mostly in correlation with the more important biological factors.

But even if we accept the warm wedges of Gunther, the problem is not yet resolved because the same Gunther has not been able to answer exactly the questions as to where these countercurrents are coming from. As his view of the conditions was limited to the winter months, it seems possible that for the summer time the origin of these

countercurrents may lay further off shore and to the north, as he indicates, so that at least the northerly one might perhaps be brought in contact under still unknown conditions with the Equatorial Countercurrent. But as for the southerly one, there seems to be no other explanations as a bending of the isotherms in the open ocean from their run SW–NE to the course NW–SE. These problems must be left open to further investigations.

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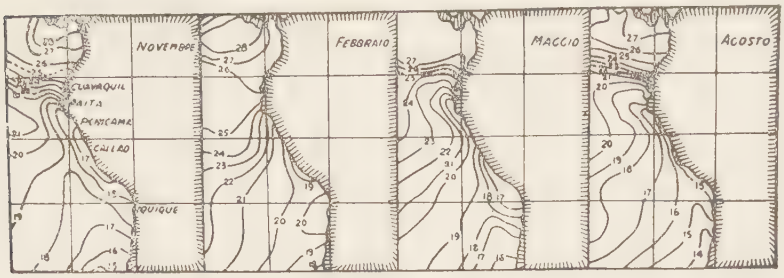
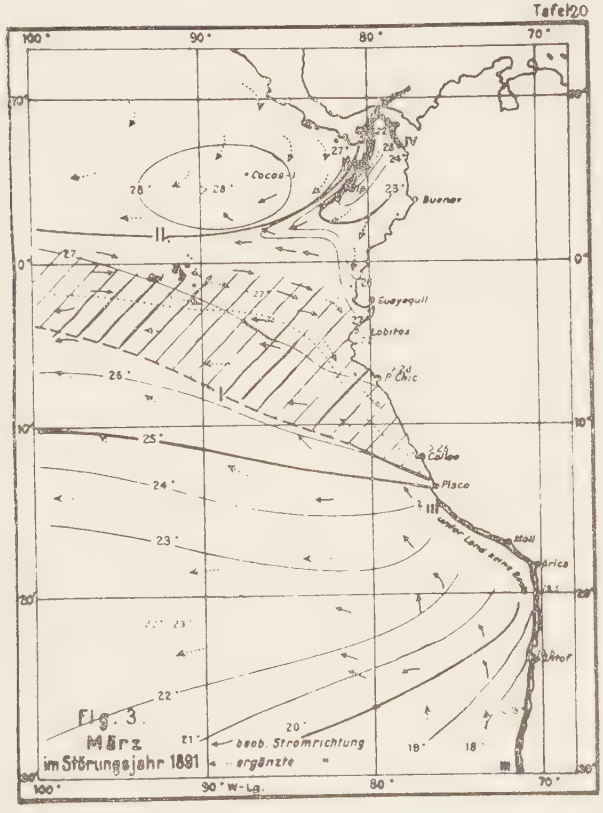


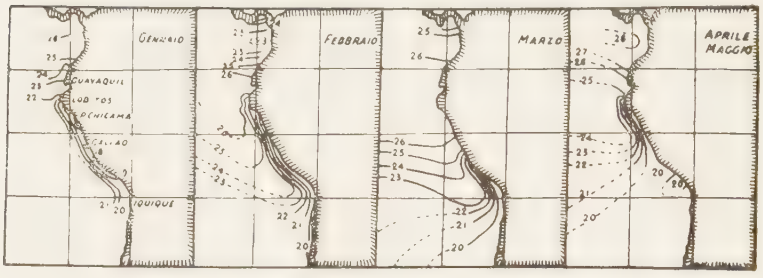
(From Bini)

FIGURE 1



(From Schott)

FIGURE 2



(From Bini)

FIGURE 3

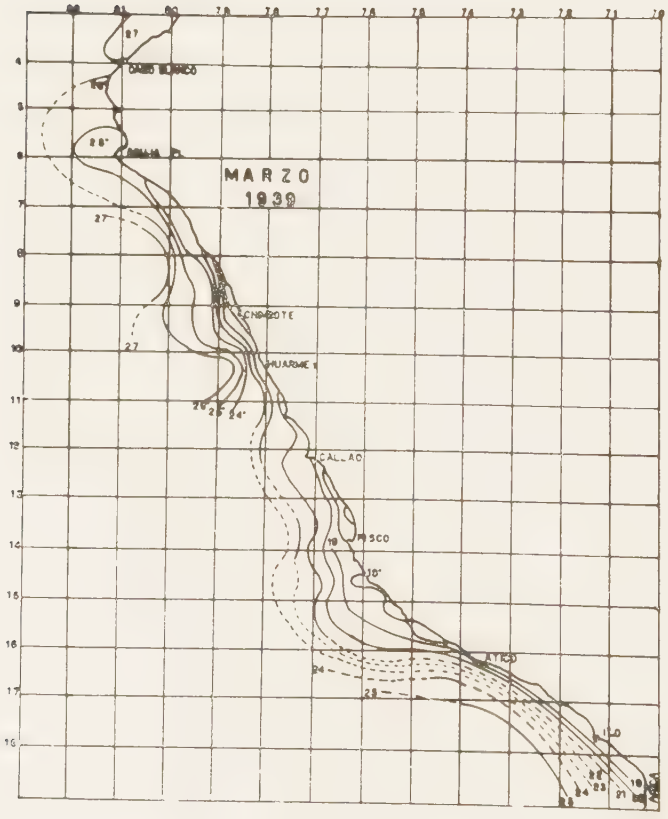


FIGURE 4

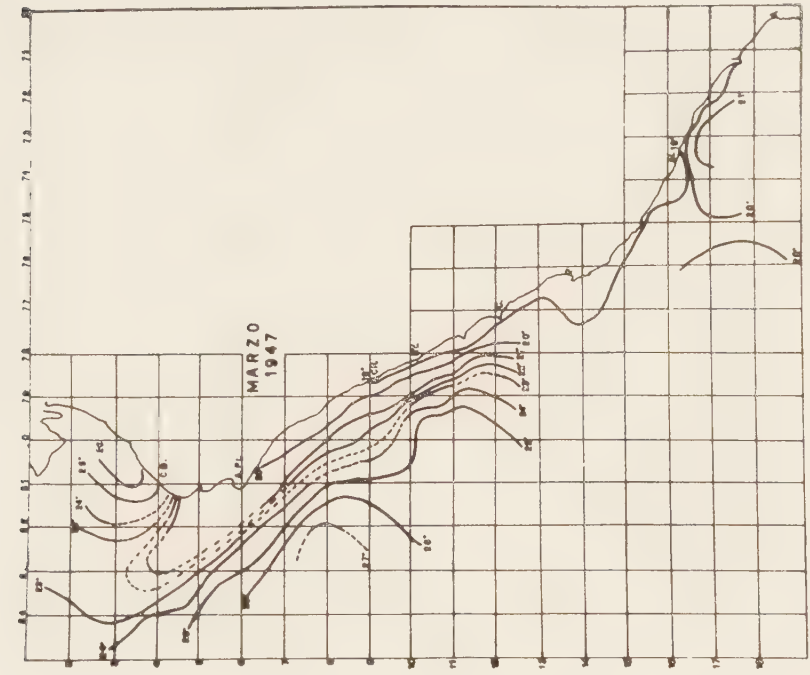


FIGURE 6

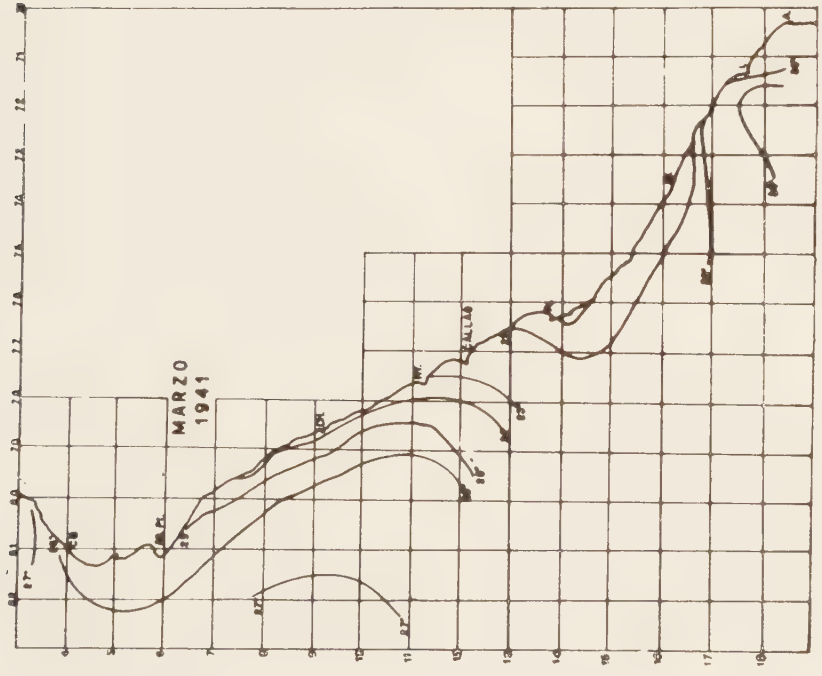


FIGURE 5

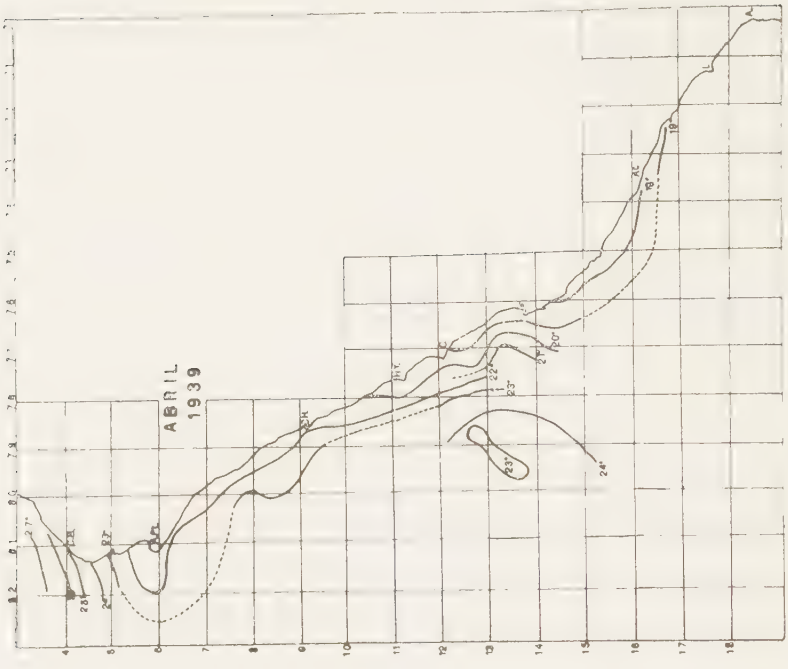


FIGURE 8

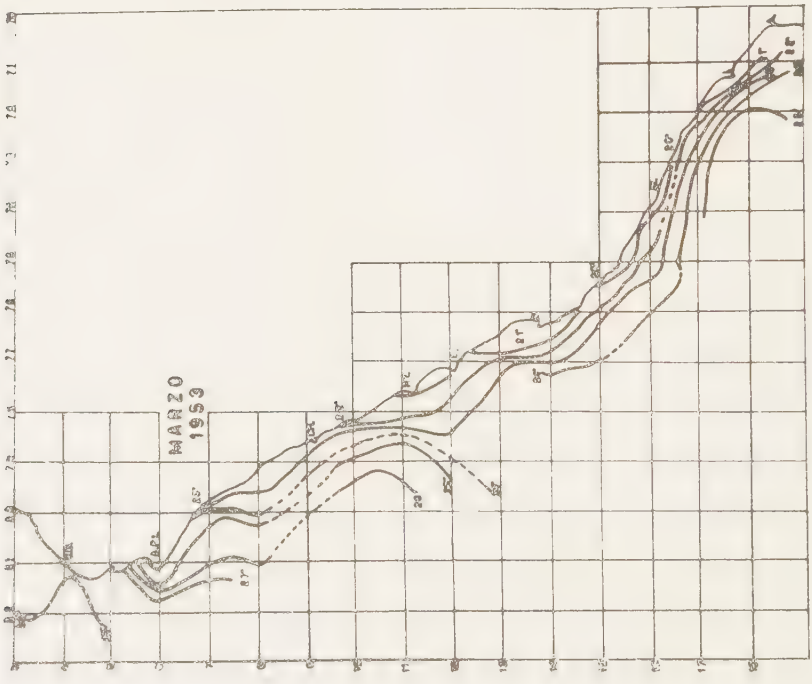


FIGURE 7

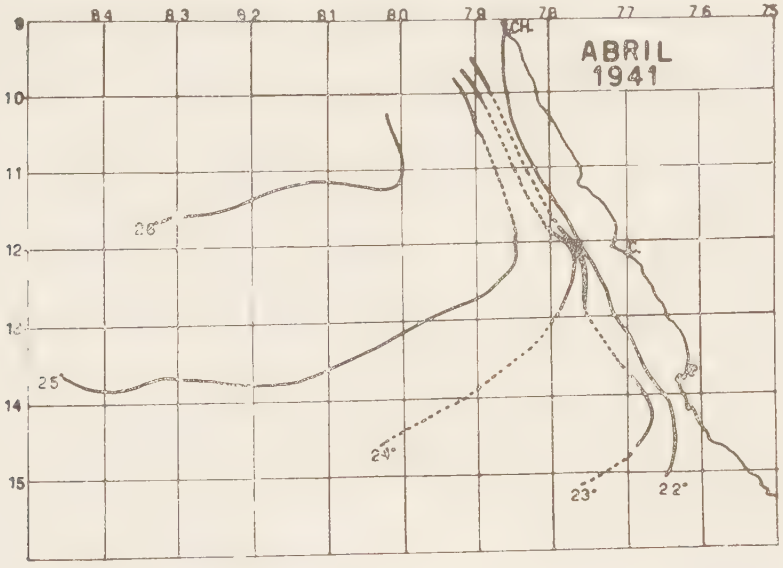


FIGURE 9

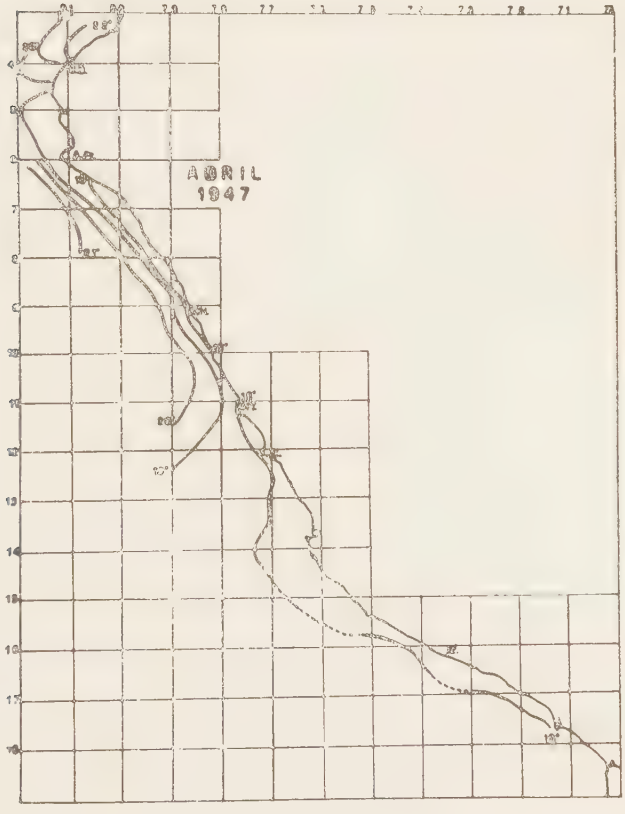


FIGURE 10

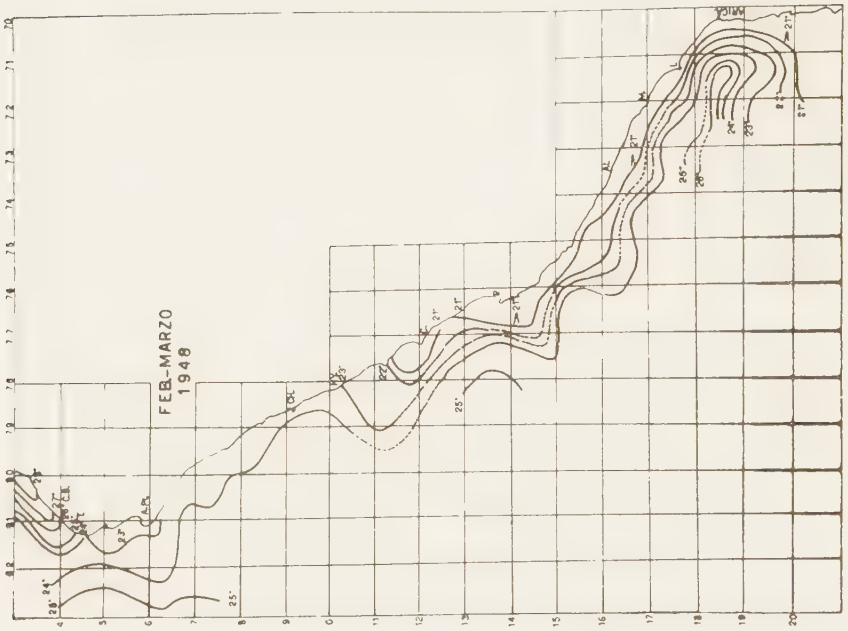


FIGURE 12

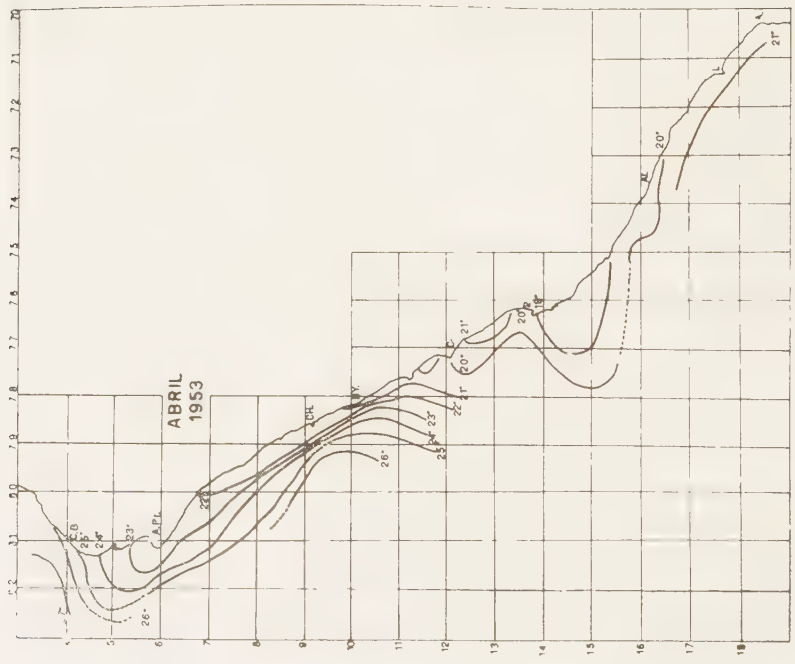


FIGURE 11

QUANTITATIVE DETERMINATION OF TUNGSTEN AND MOLYBDENUM IN SEA WATER

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As an amount of molybdenum in sea water, the values obtained by Ernst *et al.* (1), Bardet *et al.* (2) and Ishibashi *et al.* (3) are about 0.3, 3 and 10 μg per kg. of sea water respectively.

Tungsten has been detected in sea water, but the amount of it is not yet quantified. From the regularities of the amount of elements dissolving in sea water (4), Ishibashi and Shigematsu calculated and presumed the amounts of molybdenum and tungsten dissolved in sea water as about 10 μg Mo/l. and 0.4 μg W/l.

We determined the amounts of molybdenum and tungsten in sea water and found that the amount of molybdenum was almost same as that previously obtained by our thiocyanate method (3), and the amount of tungsten was about 0.1 μg per l. of sea water.

1. Colorimetric Determination of Tungsten and Molybdenum

We studied on the colorimetric procedure for trace amounts of tungsten and molybdenum by dithiol (toluene-3,4-dithiol) and established the conditions necessary and satisfactory to obtain accurate results.

Reagents:

Dithiol solution; dissolved 0.2 g. of dithiol in 100 ml. of *N*-NaOH, freshly prepared, or stored under H_2 atmosphere. The solution is stable for 2 months under H_2.

Standard tungstate solution; 10 μg W/ml. and 10.0 μg W/ml.

Standard molybdate solution; 10 μg Mo/ml. and 10.0 μg Mo/ml.

Procedure:

The solution containing molybdenum and tungsten was diluted to 50.0 ml. The 25.0 ml. aliquot of the solution was acidified with 2 ml. of *N*-HCl, then 1 ml. of dithiol solution was added to it, and heated on boiling water for about 10 minutes. After cooling, the resultant dithiol complexes were extracted with 10 ml. of butylacetate. The color intensity of butylacetate solution (Extinction E_2) was measured by using Pulfrich Photometer, the cell length 2 cm., the filter S661. To the

other 25 ml. aliquot, 1 ml. of 10% citric acid solution and 2 ml. of *N*-HCl were added, then 1 ml. of dithiol solution and heated on boiling water for 10 minutes. And the molybdenum complex was extracted with 10 ml. of butylacetate. The color intensity (Extinction E_1) was measured as above.

The amounts of tungsten and molybdenum were calculated from the following equations:

$$\mu g\ W = 58.8 \times (E_2 - E_1)$$
$$\mu g\ Mo = 83.0 \times (E_1 - 0.010)$$

It was found that through this procedure 1–40γ of molybdenum and tungsten can be determined within $\pm 0.5\gamma$ of error, and this measurements are only interfered by the presence of iron and copper.

2. Concentration of Molybdenum and Tungsten in Sea Water

For the purpose of separating and concentrating the molybdenum and tungsten in sea water, we utilize the coprecipitation method as follows:

To 0.5–15 l. of artificial sea water (5), 1–3 ml. of HNO_3 and 200 mg. of ferric iron as ferric nitrate solution were added. Then 50–100 ml. of 1*M* hexamethylenetetramine solution was added, and allowed to stand overnight to settle the precipitate. The precipitate was filtered, dried and ashed in platinum crucible at low temperature lower than 500°C. The residue was fused with small amounts of the fusing mixture ($Na_2CO_3 \pm K_2CO_3$ 1:1). The fused mass was taken up with 10–20 ml. of hot water, and filtered. The filtrate was just neutralized with $4N$-H_2SO_4 to litmus.*

The results obtained are shown in Table I, nos. 1–9.

Determination of tungsten in the presence of large amounts of molybdenum: In the presence of large amounts of molybdenum ($>10 \times$ W), tungsten was determined inaccurately by the above procedure. In sea water, the amount of molybdenum may be about 30 times larger than that of tungsten (4), so molybdenum was separated as sulfide from tungsten as follows: To the neutral solution *, 1 ml. of 50% citric acid solution and 5 drops of $4N$-H_2SO_4 were added, and H_2S bubbled vigorously for a few minutes. The sulfide was filtered through a small filter, and washed with H_2S water. The filtrate was evaporated to a few ml., filtered again through the filter, if necessary, and washed with hot water; and the solution was dried up in a platinum crucible. The residue was ashed with a small amount of sodium carbonate and fused. The mass was taken up in hot water and just neutralized with H_2SO_4. The solution was diluted to 50.0 ml., and the amount of tungsten and residual molybdenum was determined as above.

* Residual molybdenum.

The results obtained are shown in Table I, Nos. 10–16

TABLE I

RECOVERY OF MO AND W

No.	W Added (μg)	Mo Added (μg)	W Found (μg)	Mo Found (μg)
1	0.0	0.0	0.0	0.0
2	30.0	0.0	29.1	0.0
3	0.0	30.0	0.0	29.3
4	5.0	10.0	4.9	9.3
5	10.0	10.0	8.9	8.0
6	10.0	20.0	12.5	18.3
7	10.0	30.0	8.7	28.0
8	20.0	20.0	18.5	18.3
9	30.0	30.0	28.0	26.9
10	0.0	1000	<0.2	13.2 *
11	20.0	1000	18.0	7.1 *
12	30.0	1000	30.6	3.5 *
13	30.0	1000	27.1	10.6 *
14	30.0	1000	27.8	6.8 *
15	30.0	1000	26.8	10.8 *
16	30.0	1000	26.4	10.6 *

* Residual molybdenum.

The recoveries of molybdenum and tungsten in this procedure are both about 90%.

3. DETERMINATION OF MOLYBDENUM AND TUNGSTEN IN SEA WATER

About 50 l. of the sample water was taken, and acidified with 6 ml. of nitric acid; 400 mg. of ferric iron was added as ferric nitrate and thoroughly mixed. To the solution, 200 ml. of hexamine nitrate was added and thoroughly mixed. To the solution, 200 ml. of hexamine solution (containing 100 gr. of hexamine) was treated as above mentioned, and the amounts of tungsten and residual molybdenum were determined.

Molybdenum sulfide in the filter was ashed at low temperature and dissolved in sodium hydroxide. Then the amount of molybdenum was colorimetrically determined by the dithiol method.

The results obtained are shown in Table II.

TABLE II

Sea Water Taken	W Found	Mo Found		
		Residual	Sulfide	Sum
	μg	μg	μg	μg
40 l.	3.64	11.6	340	351.6
60 l.	7.90	15.8	598	651.6
40 l. + 5.0 μg W	8.97	—	—	—

The sea water was sampled on June 13th, 1952, offshore at Shirahama, Wakayama prefecture, Japan.

As seen from Table II, the molybdenum content of the sampled tungsten content is 0.10, 0.15 and 0.11 μg/l., in the average 0.12 μg/l.

We wish to thank Dr. T. Tokioka, of the Seto Marine Research, Kyoto University, for his help in sampling the sea water.

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A STUDY ON TEMPERATURE AND SALINITY OF THE SURROUNDING WATERS OF TAIWAN

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I. Introduction

Taiwan lies 150 km. off the coast of Fukien and is now a province of China. It consists of a main island and many small ones. The main island, widely known as Formosa, resembles a spindle extending from north to south with a coast line about 1500 km. The Penghu or Pescadores is a group of islands in the middle of the Taiwan Channel. Other small islands such as Penkiayu, Lanyu, Lotao, etc. are found in the vicinities along the north and east coasts of the main island.

The main island of Taiwan stands on the edge of the continental shelf of Asia and some of the small islands are of volcanic origin. The depths of the surrounding waters are, therefore, strictly different between the east and west sides of the island. In the Pacific ocean off the east coast, the slope of the bottom is very steep and the deep water reaches close to the island. At some places such as Hwalien and Taitung, the bathymetric line of 3000 meters is within 100 km. from the coast. On the other hand, the water in the Taiwan Channel is very shallow and in most parts of it the depths are below 100 meters. The topography of the bottom is very irregular and numerous rocks, reefs and banks rise from the bottom and some of them are exposed to the open air during the time of low tide. In the East China Sea off the north coast of the island, the depths are also less than 200 meters. It is much deeper in the South China Sea where we can find the deep water over 3000 meters.

Taiwan is located in the subtropical zone of the West Pacific where the North Equatorial Current turns northward and becomes the source region of the "Kuroshio" with properties of warm current. The main flow of the Kuroshio passes along the east coast of Taiwan and curves gradually northeastward far to the coast of Japan. A small part of the Kuroshio runs westward through the Bashi Channel and, after passing it, divides to two branches. One enters into the South China Sea while the other runs northward around the west coast of the island and rejoins the main flow of the Kuroshio in the East China Sea. Along the coast of Fukien province, there is a different system of current running from north to south. It has the name of China Coastal Current, and

it originates from the coast of North China and is reinforced by the outflows from the Chinese mainland. The properties of this current vary in different seasons. The water temperature is much higher during the summer time and cooler in the winter time.

The climate of Taiwan is mild with a small seasonal variation of air temperature, but the distribution of rainfall is variable at different places. During the rainy season there are great outflows from the island which influence greatly both the water temperature and salinity along the coast.

With the vast area of outstretching waters surrounding the island, Taiwan is a suitable place to serve as a base ground for oceanographical investigations. Owing to the shortage of funds and technical experts, research works have not been conveniently carried out during the past few years. The writer can only make a brief study on the distribution and seasonal variation of water temperature and salinity of the surrounding waters of Taiwan with all the data available.

II. Surface Water Temperature and Salinity along the Coast

Coastal observations of water temperature and salinity are made at nine stations situated all around the island as shown in Figure 1. The average monthly values of each station are listed in Tables I and II, which have been prepared from records covering more than ten years.

At the station of Penkiayu, which is situated at the coast of a small island some 100 km. off the north coast of the island, the water temperature is similar to the open seas. It reaches its minimum in February and maximum in July with a yearly mean of 23.2°C. and a small annual range of 7.5°C. The seasonal variation of salinity is also small and the yearly mean is 33.86 $^{0}/_{00}$.

The stations of Fukuikiao, Keelung and Bidiukiao are all found on the north coast of the main island. At these places the water temperatures are influenced by the outflows from the island. Their annual ranges are greater than Penkiayu, i.e., 12.2°C. for Fukuikiao, 10.9°C. for Keelung and 10.0°C. for Bidiukiao. The minimum and maximum water temperatures are also found in February and July respectively. Mean values of salinity are little lower than Penkiayu; they are also influenced by outflows from the island.

Along the east coast of the island, there are two stations, Hwalien and Singkang. These two stations approach more to the south and the warm current of Kuroshio comes very near to the coast. It makes the water temperatures a little higher and the annual ranges are 5.8°C. for Hwalien and 4.9°C. for Singkang. The salinity of Hwalien is 32.34 $^{0}/_{00}$ and that of Singkang is 34.07 $^{0}/_{00}$.

The station of Ngulerbei is situated at the south tip of the island stretching into the Bashi Channel. The water temperature is high and the annual range is small, that is 25.5°C. and 6.0°C. respectively. The mean salinity is 33.89 °/₀₀ with a small seasonal variation.

Kiaoshiung is a station along the southwest coast of the island facing the Taiwan Channel. The yearly mean of water temperature of 25.7°C. is the highest value among all the stations, and its annual range of 8.0°C. is also higher than the stations along the east coast. The seasonal variation of salinity is very much pronounced as it reaches its maximum of 33.82 °/₀₀ in December and falls even to 24.07 °/₀₀ in August. The reason is that at the southwest part of the island, it is very dry during the winter time and there are almost no outflows at all. But during the summer time the rainfall is quite heavy.

Peitao is a small island of the Pescadores located in the middle part of the Taiwan Channel. At that station, the yearly mean water temperature is 23.3°C., lower than at the southern stations of the main island. The annual range of 8.9°C. is little higher. This district is the most dry region of Taiwan, rainfall is very scarce during all seasons. Therefore it shows a higher monthly salinity and has a mean salinity of 33.82 °/₀₀.

III. Surface Water Temperature and Salinity of the Open Seas

As the oceanographical investigations of the surrounding waters of Taiwan were interrupted, from the beginning of World War II, we can only find some records of surface water temperature and salinity observations made before the War. The writer has made an examination of these data and gives a brief discussion below.

The surface water temperature of the surrounding waters of Taiwan is greatly influenced by the Pacific warm current of the Kuroshio and by the China Coastal Current. During the winter time, the temperature of the coastal current is much lower than that of the Kuroshio, and very close isotherms are arranged from the coast of Chinese mainland to the southeast. In summer, the water temperature of the coastal current is warmed almost up to the same level as the Kuroshio. There are only a few lines of isotherms which make the distribution very simple.

In Figure 2, showing the distribution of water temperature in February, we can see the lowest temperature of 10°C. along the north part of the China coast. It increases gradually southeastward and reaches the maximum temperature of 26°C. off the southeast coast of the island. At the south entrance of the Taiwan Channel, isotherms

curve to the north near the coast of Taiwan, which shows the warm water entering into the Channel. At the north entrance of the Channel, the isotherms curve to the west. It also shows the influence of warm current but there are still outflows from the Channel close along the north coast of the island.

The water temperature of the China Coastal Current in May is warmed up and we can find the lowest temperature of 20°C. along the north part of the coast (Fig. 3). It increases gradually southeastward and reaches its maximum of 28°C. In the Taiwan Channel the isotherms are parallel to the China Coast, but they turn gradually to parallel with the latitudes off the south and east coast of the island. From this distribution of water temperature we can find out that there are still inflows of warm current at the south entrance of the Taiwan Channel along the west coast of the island. But at the north entrance of the Channel the China Coastal Current seems more intense and the warm current leaves farther to the east.

The distribution of surface water temperature in August, which is shown in Figure 4, looks very simple. There are only two lines of isotherm in the figure. The isotherm of 27°C. is along the north part of the China Coast, while that of 28°C. separates the coast of the island of Taiwan. They all run from southwest to northeast. In this month, the water temperatures of both the China Coastal Current and the Kuroshio reach their maximum, but the former, coming from the higher latitudes, is comparatively cooler than the latter, which comes from the lower latitudes.

In the month of November, the surface water temperature along the north part of the China Coast drops down to 20°C. It increases gradually to the southeast, as shown in Figure 5, in which we can find that the isotherm of 26°C. is very close to the south and east coast of the island. But the isotherm of 27°C. is far to the southeast, leaving a great space to the isotherm of 26°C. From this manner of distribution it may be considered that the temperature of the main flow of the Kuroshio is around 27°C. and is mixed with the cooler water in the Taiwan Channel and the East China Sea.

The seasonal variation of salinity of surface water in surrounding waters of Taiwan is not so great as that of temperature. The writer gives two sketches here to show the distributions of salinity in February and August. In Figure 6, showing the distribution of salinity in February, we can find that in the east and south of Taiwan the salinity is more than 34.5 $^{0}/_{00}$, which coincides with the salinity of the Kuroshio. In the Taiwan Channel, the salinity decreases gradually toward

the coast of the mainland of China, reaching a lowest salinity of 30.0 $^{0}/_{00}$, which is influenced by coastal waters.

The salinity off the east and south coast of the island in August is a little lower than in February. The iso aline of 34.5 $^{0}/_{00}$ leaves farther to the east, as shown in Figure 7. The lowering of salinity at that region is contributed to the plentifulness of rainfall during that season. Very close to the coast of the island of Taiwan we find still lower salinity below 32.0 $^{0}/_{00}$ and 33.0 $^{0}/_{00}$. It may be contributed to the effect of outflows from the island. In the Taiwan Channel, the salinity decreases toward the coast of the Chinese mainland, where we find the lowest salinity of 31.5 $^{0}/_{00}$. This value is a little higher than in February. It is, perhaps, the result of intense evaporation effected by the high water temperature.

IV. Conclusion

From the above discussion, we can see the general feature of the seasonal distribution of surface water temperature and salinity in surrounding waters of Taiwan. It is clear that these variations are greatly influenced by the properties of different systems of currents. Unfortunately, we can not get enough data to find out the vertical distribution of these two elements and, therefore, it is impossible to form a whole idea about the nature of the currents. It needs more data of observation and further investigations to solve the problem.

TABLE I

Mean Values of Surface Water Temperature

No. of Station	Name of Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean	Range
1.	Penkiayu	20.2	19.9	20.3	21.3	22.9	26.1	27.4	27.2	26.3	23.9	22.0	21.3	23.2	7.5
2.	Fukuikiao	17.3	16.2	18.3	20.9	24.4	27.2	28.4	27.5	26.4	24.2	21.2	18.5	22.5	12.2
3.	Keelung	17.6	16.9	17.6	20.5	24.0	26.3	27.8	27.2	26.2	23.8	21.0	18.5	22.3	10.9
4.	Bidiukiao	18.0	17.5	18.3	20.0	23.5	26.5	27.6	26.9	26.4	24.2	21.1	18.9	22.4	10.1
5.	Hwalien	22.0	22.4	22.9	24.2	25.7	27.2	27.8	27.4	27.6	26.1	24.5	26.8	25.1	5.8
6.	Singkang	22.8	23.5	23.7	24.7	26.2	27.0	27.7	27.1	27.6	26.4	24.8	22.9	25.4	4.9
7.	Ngulerbei	22.5	23.1	23.2	24.8	26.7	28.1	28.5	28.0	28.0	26.6	24.5	22.5	25.5	6.0
8.	Kiaoshiung	20.6	21.3	23.3	25.3	27.5	28.5	28.6	28.2	28.6	27.4	25.1	22.5	25.7	8.0
9.	Peitao	18.3	19.3	20.7	22.4	24.6	26.3	27.2	26.7	26.5	25.2	23.1	19.8	23.3	8.9

TABLE II

Mean Values of Salinity

No. of Station	Name of Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1.	Penkiayu	34.19	34.19	34.81	34.13	33.89	33.74	33.30	33.31	33.66	33.67	33.74	34.23	33.86
2.	Fukuikiao	33.75	33.01	32.88	32.95	33.54	32.92	33.24	32.77	33.02	33.44	33.39	33.73	33.22
3.	Keelung	33.51	32.97	32.66	33.22	33.48	33.44	33.22	33.22	33.15	33.44	33.46	33.19	33.19
4.	Bidiukiao	34.28	33.74	33.96	33.78	33.66	33.49	33.16	33.00	33.24	33.45	33.76	34.22	33.64
5.	Hwalien	33.36	33.08	33.06	32.92	32.99	32.30	32.45	31.37	31.44	30.87	32.20	33.30	32.34
6.	Singkang	34.60	34.51	34.48	34.36	34.34	34.20	33.88	33.57	33.53	33.98	34.34	34.45	34.07
7.	Ngulerbei	34.57	34.54	34.69	34.53	34.43	33.54	33.53	32.24	32.75	33.33	33.98	34.56	33.89
8.	Kiaoshiung	32.59	31.38	32.36	32.94	31.18	28.96	24.76	24.07	29.65	32.48	32.97	33.82	30.31
9.	Peitao	33.60	34.18	34.14	34.14	34.16	34.05	33.18	33.17	33.49	33.78	34.04	33.76	33.82

Fig. 1. Location of Coastal Stations

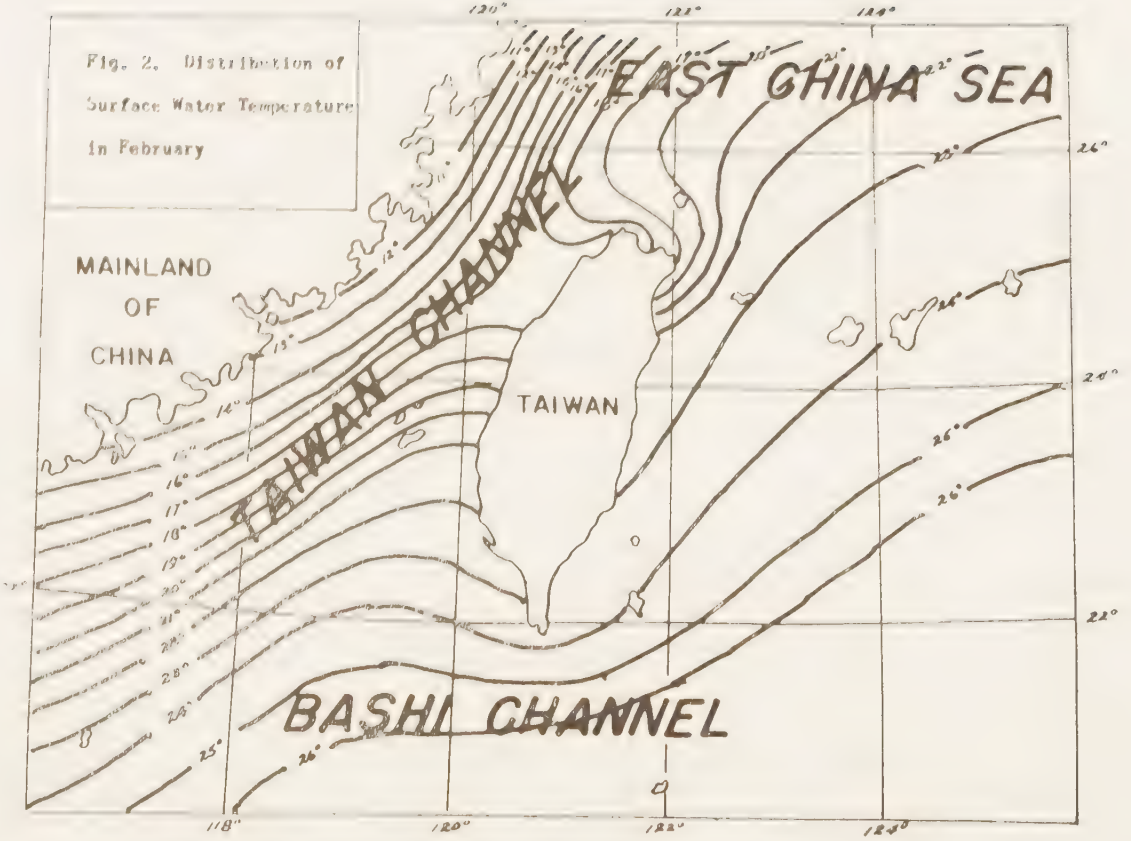

Fig. 2. Distribution of Surface Water Temperature in February

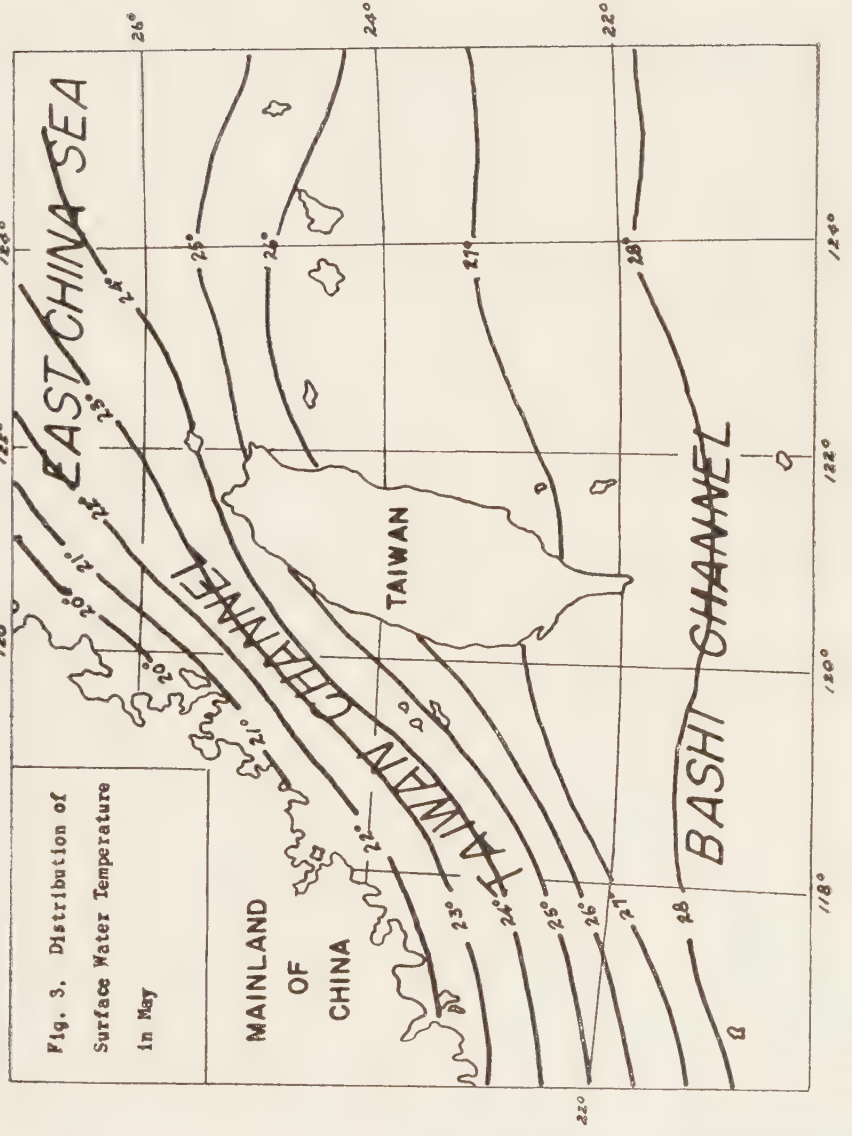

Fig. 3. Distribution of Surface Water Temperature in May

Fig. 4. Distribution of Surface Water Temperature in August

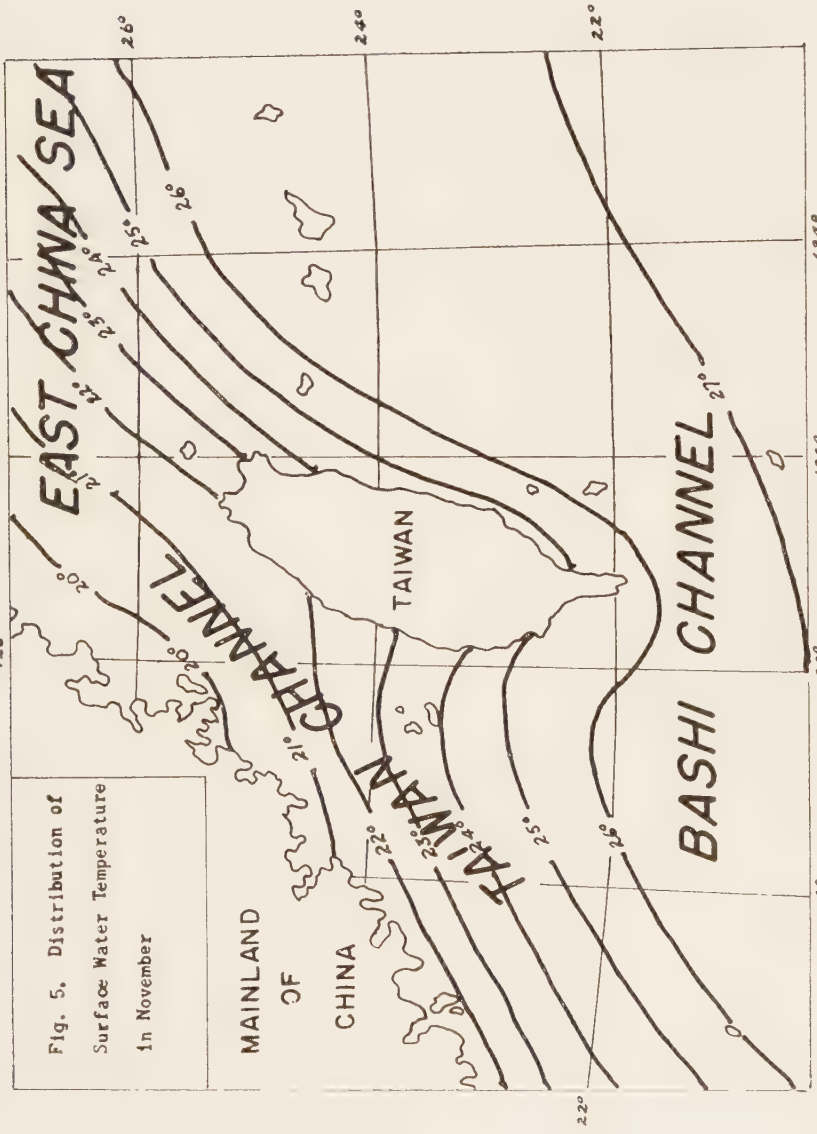

Fig. 5. Distribution of Surface Water Temperature In November

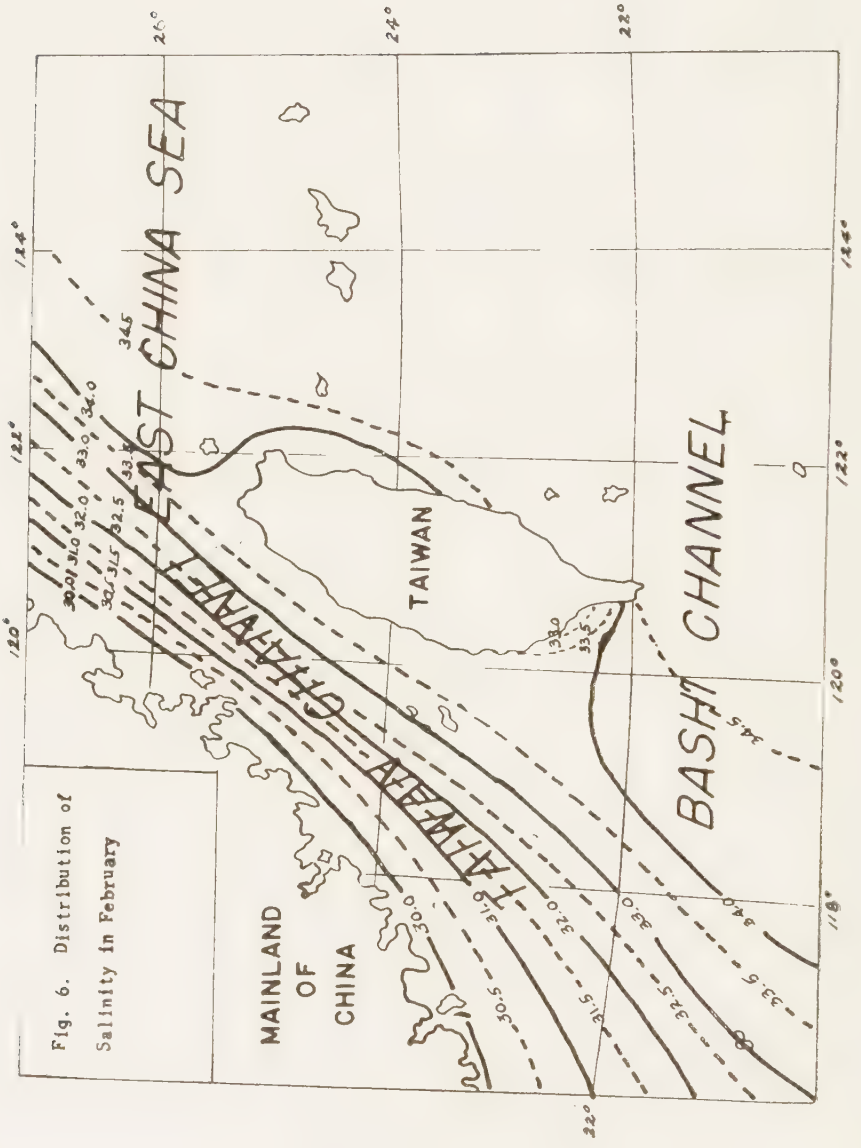

Fig. 6. Distribution of Salinity in February

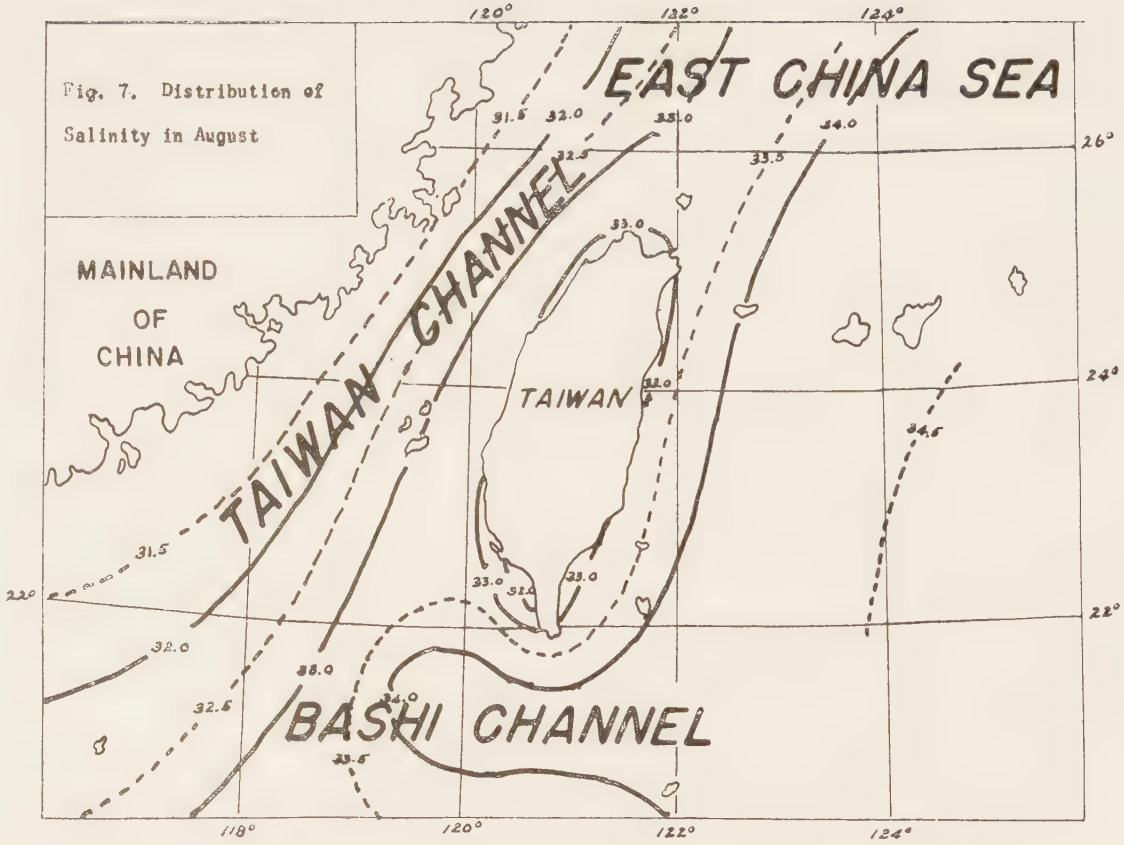

Fig. 7. Distribution of Salinity in August

ON THE FLUCTUATION OF THE KUROSIWO AND THE OYASIWO

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Abstract

Using the area occupied by the oceanic current in a fixed section, the author represents on a graph the intensity of the Kurosiwo and the Oyasiwo as mentioned in his previous paper. The occupied area has one or two maxima a year. The period is about seven to nine months as shown in accompanying figure.

1. Introduction

To represent the intensity of the Kurosiwo and the Oyasiwo numerically, the author adopted substitute quantities which are easily calculated; they are the ratios of the area occupied by the Kurosiwo or the Oyasiwo to the whole observation area in the fixed section on the parallel of 38°18′N. In the case of the Kurosiwo the calculation is limited to 300 m depth, and in the case of the Oyasiwo to 600 m depth.[1] The author will copy the values published by the Central Meteorological Observatory for the sea conditions, and will compare these with his quantities, the ratios of the Kurosiwo and the Oyasiwo.

2. Comparison of the Results Obtained by the Author's Method with the Actual Oceanographical Conditions

The results obtained for the ratios of the Kurosiwo and the Oyasiwo are shown in the following figure. If these values correspond to the actual oceanographical conditions with small differences, we would have an important means to represent and forecast oceanographical conditions.

The actual oceanographical conditions quoted here were investigated by the usual method using the distribution patterns of temperature, chlorinity, etc.

We observed that the intensity of the Kurosiwo was less in 1949 than in the preceding year. In 1948 the Oyasiwo was somewhat stronger in early summer and late autumn, but it was weaker in other months. On the other hand, the Kurosiwo was stronger, especially in summer, and the warmer anomaly of the surface water temperature was largest in August.[2] The ratio shows that the Kurosiwo's area was large in late

September and in October. Perhaps the ratio in August can be conjectured to be large from the tendency of the figure, but observations were not done before September.

In 1949 the Kurosiwo had average or somewhat stronger intensity in summer, and the warmer anomaly of surface water temperature was largest in October. The figure shows that the ratio of the Kurosiwo had maxima in June and July, and that their value was usual for summer maxima. Another maximal value appeared in September, after the rainy season. This was smaller than that of the preceding year. This fact indicates that the Kurosiwo was weaker than in the preceding year. In these years, the available data were scanty due to the imperfection of our equipment.

In 1950 the Kurosiwo became stronger rapidly from April, with an extremely warm surface temperature in summer. The warmer anomaly of surface temperature, which was largest in May and August, was limited to the somewhat upper layers in summer. The Oyasiwo became stronger rapidly in April, weakening from middle August and growing stronger again in September. But it was still warmer in the warm current region and colder in the cold current region than in the average year.[4] The ratio of the Kurosiwo grew larger from April and May, and it was very lage in August and September, growing smaller rapidly in October and tending to zero in December. The ratio of the Oyasiwo was large in spring and in early summer also, but it was small in summer, growing large again from September, and reaching a maximum in December.

In 1951 the Kurosiwo became stronger rapidly from April, but weakened from middle June to July; the temperature anomaly was lower than the average. But its temperature became higher again from late July to August. It stopped to rise, maintaining the average or somewhat lower value in September and October. But it became stronger from November especially and kept the intensity till February 1952; so the warmer anomaly of temperature, warmer than those of 1950 and 1951, was observed in February, and this vigorous Kurosiwo weakened in March and April. The Oyasiwo had less intensity than that in the preceding year in early Spring, but it became stronger in early July, weakening in August and again becoming stronger in September, then weakening from October till February.[5] The ratio of the Kurosiwo grew large rapidly from April and was largest in June, growing smaller from July but larger again from November, becoming largest in February, 1952.The ratio of the Oyasiwo had a maximum in December, 1950, and after that it grew small and was smaller than in the preced-

ing year. It was large in July, September and late October, and small again from November till February.

In 1952 the Kurosiwo was strong from the last decade of November till February and became strong again in early April along the meridians 143°E and 149°E, reaching the average intensity in June and July, but the warm current stopped spreading northwards in August at a lower anomaly of temperature. But it grew warmer again and reached the average temperature in September. After that it had the average intensity. The Oyasiwo was strong along the meridians 142°E and 147°E in March and April. In August, the Oyasiwo ran southwards strongly along the 145°E meridian.[6] The ratio of the Kurosiwo became smaller from February and was generally small all year with a maximum in September, which is of the average value in summer. The ratio of the Oyasiwo had maxima in April, July and September.

The ratio of the Kurosiwo seems to vary periodically. If there were a maximum in February, 1950, though it was not observed owing to bad weather condition, the maxima of the Kurosiwo's ratio have the following time series: Oct. 1948, 9; July 1949, 7.5; Feb. 1950, 7.5; Sept. 1950, 8.5; June 1951, 8; Feb. 1952, 7.5; Sept. 1952.

The period is about seven–nine months. On the other hand, the period of the wind stress shear is about six–eight months.[7] The periods of the oceanic current and the wind do not coincide with each other, and the reason why the current's period is lengthened will be found in a complex combination of the wind-driven, thermo-haline circulation, etc.

3. Conclusion

By the comparison mentioned in the above section, we can recognize that the area occupied by the oceanic current is an important measure to represent numerically the intensity of the current or the oceanic state, and the period of the Kurosiwo's fluctuation is about seven–nine months. Though we may have to make further investigation of the difference in the periods between the Kurosiwo and the wind, it is certain that we have made a step toward the forecast of oceanic conditions.

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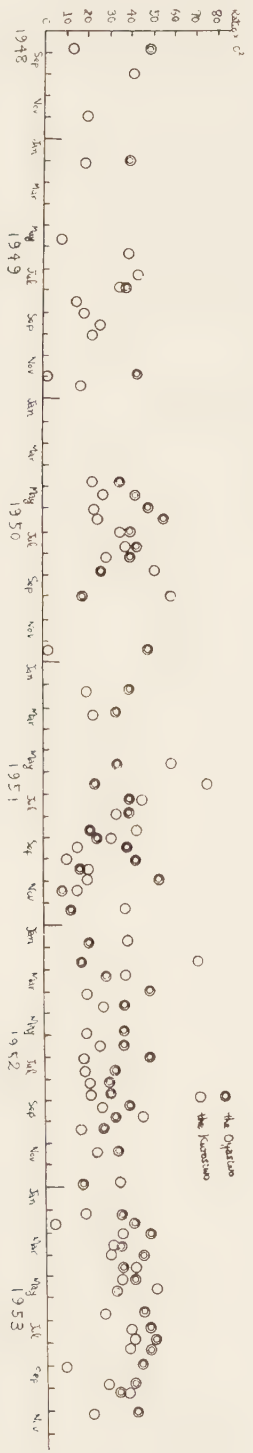
the Oyasiwo
the Kurosiwo

A REPORT ON THE OCEANOGRAPHICAL OBSERVATIONS IN THE ANTARCTIC OCEAN CARRIED OUT ON BOARD THE JAPANESE WHALING FLEET DURING THE YEARS 1946–1952

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Abstract

The chief characteristics of the oceanographical conditions of the Antarctic Ocean given in the present treatise are founded on the observations taken on board the Japanese whaling fleet during the years 1946 to 1952. Among many interesting facts found by the Japanese Fleet, we may mention these significant points.

1) In the Antarctic Ocean, the temperature and chlorinity graph of the sea surface increases in the shape of a parabola as the distance from the pack-ice line increases.
2) Ocean currents computed from dynamic calculation near Scott Island in 1949 show eastward flow to the north of 67°S, and southward flow along the 180° line to the south of 67°S.
3) The insignificance of the Antarctic circumpolar water is due to bottom topography and to small clockwise circulations.
4) The boundary of two currents is a good whaling ground, even in the Antarctic Ocean; and in the homogeneous water area good whaling is not expected.

A NEW JAPANESE G.E.K.

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(1) Introduction

An insulated conductor is drifted along the ocean current flows, cutting the geomagnetism; then there must occur an electric motive force by Faraday's electro-magnetic induction law. If this e.m.f. can be picked up, the velocity of the conductor, which is the same as that of the current, may be known, as the distribution of the geomagnetism is already known all over the world. Electromotive force will be induced in the current too, but it is dropped as negligible, because the sea water is conductive and its volume is immensely large, even in the superficial part, as Stommel proved. If both ends are shortened to the sea water, an electric current flows through the wire and sea water.

We utilise this e.m.f. for measuring the velocity of the current as above mentioned.

In practice, there remain the following difficulties:

1. Sea water is an electrolytic solution, so a contact of metal introduces an ionization potential and the measuring is disturbed very much. We conquered this trouble by using a special electrode of silver-silver chloride.

2. The resistance of these electrodes is very high and the electric current decays them even as small as less than 0.1 micro-ampere. These problems have been easily solved since the electronic potentiometer was produced in Japan.

We composed a system of measuring apparatus from a couple of specially designed electrodes, an electronic potentiometer, a set of leading cable made by special order, and a switch pannel having switches, electric condensers, etc.

Some confirming experiments were done very cautiously on the characteristics of the electrodes on the temperature effect, density effect of salt water and some points of handling for practical uses.

(2) Practical Method of Measurement

The electrodes are connected directly to the pannel board of the potentiometer by two lines of the specially made cord of a single core. The length of the cord is 200 m. and 100 m. respectively for the elec-

trodes, i.e. the latter is 100 m. distant from the former. Then they are driven into sea and the cord is tied to the ship as the shorter electrode stays about 100 m. from the stern of the ship.

These works are conducted when the ship is running. When all have been prepared well, measurements are begun.

At first and at last, the zero point confirmed by the longer cord is shortened till the length becomes the same as that of the shorter one, i.e. the two electrodes lie side by side. We got the constancy of the zero point in the range of 0.2 mV or less, which corresponds to about 0.1 kt of the current velocity.

After confirmation of zero point, we prolong the longer cord to full length. Then the meter indicates some millivolt, which shows the e.m.f. produced by the component of the ocean current perpendicular to the direction of the ship course. Then we turn the course to another direction, preferably near right angle. When the needle of the meter sets in the new direction, it indicates the e.m.f. of the component perpendicular to the new direction. Under the assumption that the current is constant during the turning of direction, or the two components can be considered to be those of the same vector of the current velocity, we can compose the total velocity from the two components of velocity and the direction of the course of the ship, which is known by the compass.

The composition of these vectors is, however, a little different from the ordinary method. We draw the respective vectors of the components, from the same point in the middle of turning. The scalor amount is given from the reading of the potentiometer and the direction must have been informed from the bridge of the ship, whenever the reading is taken. Then, the intersection of the two perpendiculars from the respective points of the component vectors must be the top of the composed vector, drawn from the same origin.

In such a way, we can measure easily the vectorial velocity of the ocean current from the moving ship. For the check of these values, we compared the values of the amount of the drift of a ship by the current measured by our method and by calculation from the positions of the ship at the beginning and the end. The position of the ship was confirmed by triangular survey by a sextant.

(3) Practical Measurement of Ocean Current

1. Off the point Nojima-zaki.

Nojima-zaki is situated at the south edge of the Bohsoh Peninsula, Chiba prefecture, Japan. The warm current "Kuroshio" flows along

the south side of the main island of Japan and passes through the row of Iz islands to Nojima-zaki. We attemped the first experiment of the measurement on Kuroshio, off the Point Nojima-zaki.

Three square courses and two zig-zag courses were made as shown in Figure 1. At every point of turning, the measurement was tried. The velocities measured by our method are shown in the following table. The points of survey stand in four rows, so the values may be classified into four series. The series 4 farthest right is considered to be near the edge of the current.

Velocity of Kuroshio off the Point Nojima-zaki

Position	No. of Series	Velocity kt	Mean kt
left (north)	1	1.2, 1.6, 1.3	1.37
middle	2	1.5, 1.5, 1.1, 1.4, 1.4, 1.3	1.37
right (south)	3	1.3, 1.6, 1.5, 1.3, 1.0	1.34
edge	4	0.8, 0.9	0.85

On the other hand, we found the amount of drift of the ship from the difference between the positions, surveyed by the triangular method to land, and those calculated from ship velocity, time duration and direction.

At every drift is 1.1 kt, 1.3 kt and 1.4 kt, and the vectorial mean is 1.26 kt. Comparing these values of drift of the boat with the former values 1.37 kt, difference was found to be only 0.1 kt and the direction coincided with the accuracy of the compass, 5°.

In conclusion, the accuracy of triangular survey by the sextan method is rough as known generally, but the two values coincided well. Furthermore, the mean values of the three series of the G.E.K. method coincide with each other very well. The individual values differ from the mean values of the 1.37 kt, with the range of error as ±0.25 kt This accuracy has not been confirmed till now with more accurate methods, yet the statistical values will explain well about the accuracy.

2. Along Iz Island.

In the south of the Iz Peninsula, Shizoka Prefecture, there lies a row of islands from north to south. We call them Iz 7 Islands. The warm current Kuroshio flows through this row of islands from west to east. For the second experiments, we surveyed Kuroshio around this row of islands between two peninsulas, Bohsoh Peninsula and Iz Peninsula as shown in Figure 2. Figure 3 shows the recording chart. The numerical figures show the time; those between arrows in middle circle

are the millivolt produced in the cord. 1.74 millivolt corresponds to 1 knot around this district. In this experiment, we found many new facts.

1) Kuroshio flows from S.S.W. to the nose of Iz Peninsula and changes its direction to N.E.E. with a velocity of 1.7 kt to 1.3 kt.

2) Though we missed to survey well, it can be said from our other results that this current collides against Ohshima Island of Iz 7 Islands and separates into two ways.

One flows N.E. and reflects at the Sagami Bay to S.E. Another one flows E. and passes through the south side of Ohshima, and changes its direction to S.E. into the center of Pacific Ocean.

3) The former passes through between Ohshima and Nojima-zaki to S.E. with velocity 1.3 kt.

4) It is imagined that a still part exists behind Ohshima Island, as a center of vortex.

5) A part of the two flows shown in 1) may join after this vortex and flows N.E.E. to some point off Nojima-zaki, which was surveyed in the first attempt.

6) We found a current which flows S.E. with velocity over 3.3 kt at a point about 34°20′N., 139°10′E. This current comes, perhaps, from a branch of the current through the south side of Ohshima shown in 2). Details of this current are shown in Figure 4.

(4) Conclusion

1. We constructed a new G.E.K. with special silver-silver chloride electrode, an electronic potentiometer, special cord made to order, and other accessories.

2. The calibration shows that this has a good accuracy compared with the drift method, surveying land points by a sextan to confirm the real position of the ship.

3. Three series of the measured value by G.E.K. off the Point Nojima-zaki show the same mean value 1.37 kt from observations of over one dozen, and the individual values deviate ±0.25 kt from the mean value.

4. Survey with G.E.K. along Iz Islands showed many details about the construction of Kuroshio.

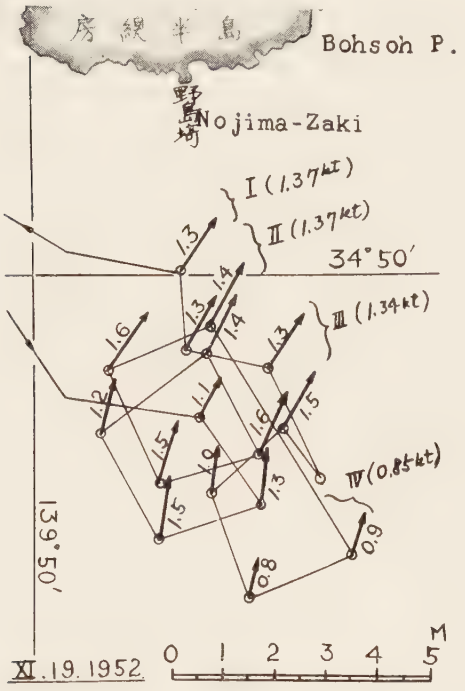

FIGURE 1

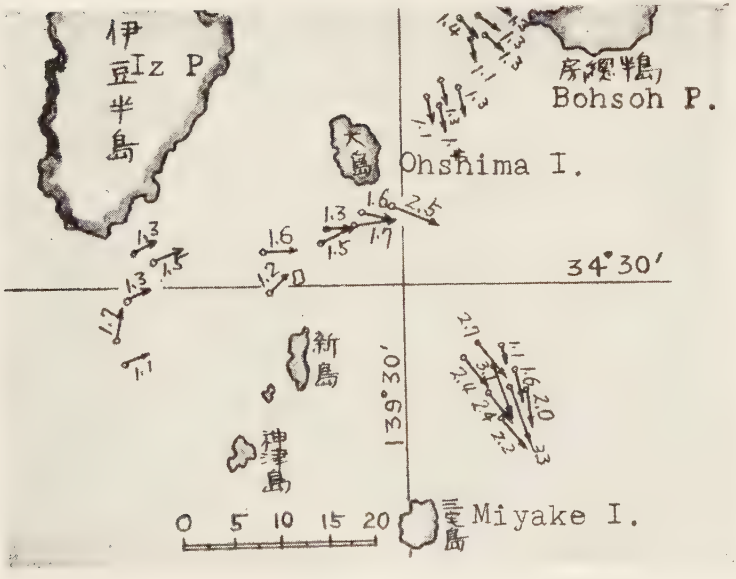

FIGURE 2

FIGURE 1

FIGURE 2

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CORRIGENDA

Page 369—last line, for "Colloqium" read "Colloquium"
Page 431—line 27, for "*fuscopuntata*" read "*fuscopunctata.*"
Page 446—line 3, for "Kehler" read "Koehler."